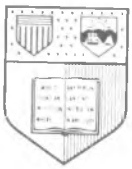

Cornell
University

ANNOUNCEMENTS

Graduate School
Physical Sciences

1968-69

Calendar, 1967-68

FALL TERM	1967–68
Registration, new students	Sept. 8
Registration, old students	Sept. 9
Fall term instruction begins, 7:30 A.M.	Sept. 11
Last day for filing statement-of-courses form and change of committee form and for new students to file nomination of committee form	Sept. 22
Last day for old students to take Admission to Candidacy Examinations in order to have them considered as of the beginning of the term	Oct. 11
Language examinations: French, German, and Russian	Oct. 28
Last day for change of course registration	Nov. 17
Thanksgiving recess: Instruction ends, 1:10 P.M.	Nov. 22
Instruction resumes, 7:30 A.M.	Nov. 27
Fall term classes end, 1:10 P.M.	Dec. 16
Christmas recess	
Last day for completing all requirements for January degrees	Dec. 27
Independent study period begins	Jan. 3
Final examinations begin	Jan. 8
Final examinations end	Jan. 16
Intersession begins	Jan. 17
SPRING TERM	
Registration, new students	Jan. 26
Registration, old students	Jan. 27
Spring term instruction begins, 7:30 A.M.	Jan. 29
Last day for filing fellowship and scholarship applications for the following year	Feb. 1
Language examinations: French, German, and Russian	Feb. 3
Last day for filing statement-of-courses form and change of committee form and for new students to file nomination of committee form	Feb. 9
Last day for old students to take Admission to Candidacy Examinations to have them considered as of the beginning of the term	Mar. 1
Spring recess: Instruction suspended, 1:10 P.M.	Mar. 23
Instruction resumed, 7:30 A.M.	Apr. 1
Last day for change of course registration	Apr. 5
Language examinations: French, German, and Russian	Apr. 20
Last day for completing all requirements for June degrees	May 10
Spring term classes end, 1:10 P.M.	May 11
Independent study period begins	May 13
Final examinations begin	May 20
Final examinations end	May 28
Commencement	June 3
SUMMER	
Summer Research period begins	May 29
Registration for Summer Session	June 17 (8-week) June 26 (6-week)
Last day for filing statement-of-courses form and change of committee form and for new students to file nomination of committee form	July 5
Language examinations: French, German, and Russian	Aug. 3
Summer Session ends	Aug. 11
Last day for completing all requirements for September degrees	Aug. 16
Summer Research period ends	Sept. 12

(Please see inside back cover for the 1968–69 Calendar.)

Cornell University

Graduate School
Physical Sciences

1968-69

ADMINISTRATION

UNIVERSITY

James A. Perkins, President of the University
Dale R. Corson, University Provost
Mark Barlow, Jr., Vice President for Student Affairs
John E. Burton, Vice President — Business
Lewis H. Durland, University Treasurer
W. Keith Kennedy, Vice Provost
Franklin A. Long, Vice President for Research and Advanced Studies
E. Hugh Luckey, Vice President for Medical Affairs
Thomas W. Mackesey, Vice President for Planning
Paul L. McKeegan, Director of the Budget
Robert D. Miller, Dean of the University Faculty
Steven Muller, Vice President for Public Affairs
Arthur H. Peterson, University Controller
Robert L. Sproull, Vice President for Academic Affairs
Neal R. Stamp, Secretary of the Corporation and University Counsel

GRADUATE SCHOOL

W. Donald Cooke, B.S., M.S., Ph.D., Dean of the Graduate School
Paul R. Leurgans, B.A., M.S., Ph.D., Associate Dean of the Graduate School
Frank W. Young, B.A., M.A., Ph.D., Secretary of the Graduate Faculty

General Committee

Professor Ralph Bolgiano, Jr. (Member-at-Large), term expires 1969
Professor C. L. Comar (Member-at-Large), 1969
Professor Charles F. Hockett (Member-at-Large), 1967
Professor R. D. Miller (Member-at-Large), 1967
Professor Isaac Rabinowitz (Humanities), 1967
Professor S. Cushing Strout (Humanities), 1969
Professor Philip J. McCarthy (Social Sciences), 1967
Professor John M. Roberts (Social Sciences), 1969
Professor J. Thomas Reid (Biological Sciences), 1967
Professor Harry W. Seeley, Jr. (Biological Sciences), 1969
Professor Robert A. Plane (Physical Sciences), 1967
Professor E. L. Resler, Jr. (Physical Sciences), 1969

GRADUATE SCHOOL OF MEDICAL SCIENCES

1300 York Avenue
New York, New York 10021

John E. Deitrick, M.D., Dean of the Graduate School of Medical Sciences
Julian R. Rachele, B.A., M.A., Ph.D., Assistant Dean of the Graduate School of Medical Sciences

UNIVERSITY PROFESSORS-AT-LARGE

Professors-at-Large are distinguished nonresident members of the University Faculty. During short visits to the campus, of up to a month's duration, made at irregular intervals, they hold seminars, give public lectures, and consult informally with students and faculty.

Raymond Aron
Sir Eric Ashby
Daniel Cosio Villegas
Manfred Eigen
Gino Gorla
L. S. B. Leakey
Barbara McClintock
Sir Peter Medawar
Charles S. Singleton
Georg Henrik von Wright

CORNELL UNIVERSITY ANNOUNCEMENTS

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Contents

Cornell University

GRADUATE EDUCATION AT CORNELL

Graduate education at Cornell is based on the principle that no objective of a university lies deeper in its tradition or springs higher in its aspiration than does the nurture of scholarship. The advancement of learning, the methods of learning, and the criticism of learning occupy the highest reaches of university life and work. Graduate education brings into fruitful contact the most distinguished scholars and the most advanced students, that learning may be shared and that wisdom may be at least glimpsed.

The Graduate School provides an environment within which scholarly capability is encouraged to emerge, thrive, and transmit itself. The School arranges a set of conditions congenial to the student who is prepared to profit from the availability of advanced courses of study; the opportunity for sustained reflection; the companionship of active, full-time fellow students; the most highly developed libraries, laboratories, and other facilities for research; the prospect of independent discovery or recovery, of evaluation or revaluation; the daily presence of distinquished teachers; and the hope of attaining a firmly based structure of knowledge and a free and independent habit of judgment.

Freedom and independence are key qualities of scholarship, and graduate studies at Cornell are ordered so as to preserve them for both teacher and student. The Cornell principle is that scholars are begotten by other scholars, that judgments are formed by associating with the best judges, that learning lives in the unbroken succession of the learners and the learned, that genuine scholarship is always humane and rests ultimately on personal teaching and personal learning, that success in graduate studies must consist of satisfying the professor rather than a mute schedule of requirements. Graduate School standards are high, but they are maintained there not by the pronouncements of an office but rather by the men after whom such standards are themselves fashioned.

The Cornell graduate student selects not only the study he wishes to pursue, but also the scholar under whose tutelage he wishes to pursue it. The candidate himself, no one else, makes the choice. Some candidates when they apply for admission have in mind the man or men with

whom they wish to study. Those who do not are granted, under a temporary adviser, a semester in which to form an acquaintance and to come to a decision. The supervising professor is called the student's chairman. The chairman and his associate or associates, also chosen by the student, form the student's Special Committee. All such matters as the outlines of study, the observation of progress, the setting of general examinations, the conduct of the thesis, and other exercises leading to a graduate degree are determined within this small circle — the student and the professors he has selected to direct him. So successful is this arrangement and so strongly does Cornell believe in it, that the Special Committee enjoys extraordinary freedom and independence in conducting the student to his degree. The Graduate School sets no course requirement, no credit-hours requirement, no grade requirement. Within the broad agreements of the Graduate Faculty concerning residence, oral examinations, and thesis, the student will be recommended for his degree whenever his Special Committee judges him ready to receive it. When the Committee is satisfied, the requirements are.

The Cornell Graduate School has an enrollment of 3,300 students, and the Graduate Faculty consists of about 1,100 members. In contrast to many other graduate schools, approximately 98 percent of the students are full-time degree candidates, with the majority in programs leading to the Ph.D. degree.

ADMISSION

APPLICATIONS

To be considered for admission to the Graduate School an applicant must (1) hold a baccalaureate degree granted by a faculty or university of recognized standing or have completed studies equivalent to those required for a baccalaureate degree at Cornell, (2) have adequate preparation for graduate study in his chosen field of instruction, (3) have fluent command of the English language, and (4) present evidence of promise in advanced study and research. Students from United States colleges and universities should be in at least the top third of their graduating class.

Applications for admission should be requested from the Graduate School, Sage Graduate Center, Cornell University. Two letters of recommendation from the applicant's major instructors, official transcripts of record from all the institutions of higher learning attended, and, where required, the Graduate Record Examination or the Miller Analogies Test scores complete the application.

The applications from United States citizens and from foreign applicants who reside in the United States or Canada must be accompanied by a $15 nonrefundable application fee. Foreign applicants residing elsewhere who have been accepted for admission must pay this fee before registration.

Foreign applicants whose native language is not English and who have not received their secondary school or university education in the English language must take the Test of English as a Foreign Language by arrangement with Educational Testing Service, Princeton, New Jersey 08540, U.S.A., or the Michigan English Language Test by arrangement with the English Language Institute, University of Michigan, Ann Arbor, Michigan 48104, U.S.A. The test scores must be reported directly by the testing organization to the Graduate School as part of the essential application information, and no final action on applications will be taken until the scores have been received. Both testing programs are available throughout the world. Information on times and places for administration of the tests may be obtained directly from the addresses given above. Since these tests are diagnostic, admission to those applicants whose scores indicate unsatisfactory command of English may be denied or may be made contingent upon evidence of improved command of English.

If English has been the medium of instruction in the secondary school or university, a statement to this effect signed by a responsible officer of a United States Embassy or Consulate or by an appropriate official of the educational institution involved should be sent to the Graduate School.

All applicants for admission and fellowship consideration are urged to take the Graduate Record Examination (GRE) Aptitude (Verbal and Quantitative) Tests of the Education Testing Service, and to have the scores sent to the Cornell Graduate School as part of their application materials. Information about the times and places of test administrations may be obtained directly from the Educational Testing Service, Princeton, New Jersey 08540. The Field listings, pages 48–175, should be consulted for Fields requiring the scores of both the Aptitude Test and the pertinent Advanced Test.

CATEGORIES OF ADMISSION

1. Degree Programs

It is expected that most applicants for admission will pursue a program for an advanced degree. Except under unusual circumstances, those who already hold an advanced degree are not permitted to apply for the same degree. Applicants may specify candidacy for the Master of Arts or Master of Science or one of the professional Masters' degrees listed on pages 176–179. However, since Cornell has a strong commitment to doctoral work, most students are encouraged to enroll in a doctoral program. In some fields, students registered in a doctoral program may be required to seek a Master's degree as an initial step in the program.

2. Provisional Candidacy

Under circumstances in which it is difficult to evaluate the academic background of qualified applicants, they may be admitted to *provisional* candidacy. Ordinarily only one semester of study in provisional candidacy is permitted, and the student who fails to qualify for candidacy at the end of that time may be requested to withdraw from the University.

3. Noncandidacy

When staff and facilities are available, the Graduate School will admit some applicants who do not intend to work toward an advanced degree at Cornell but who have special objectives for formal study or scholarly work at the graduate level. In order to be admitted for study in noncandidacy, the applicant must satisfy all the entrance requirements expected of degree candidates. Registration in noncandidacy is restricted to two semesters.

CHANGE OF STATUS

A student who wishes to change his status from nondegree candidacy to regular candidacy or from one degree or Field to another, or who, after receiving the Master's degree, wishes to undertake candidacy for the doctorate, must submit a request in writing to the Dean of the Graduate School asking for transfer to the new status. Reasons for the change in status should be given. Provisional candidacy is automatically reviewed at the end of each semester, and no letter is necessary in this instance.

DEGREE REQUIREMENTS

THE SPECIAL COMMITTEE

The general degree requirements of the Graduate School are kept at a minimum in order to give the student maximum flexibility in choosing a desirable program of studies. Since progress in graduate study depends so much on the individual student's situation, there are no course, grade, or credit requirements imposed by the Graduate School. The student's program is developed in conjunction with a Special Committee chosen by the student from the area of studies of interest and is designed to best fit the specific needs and desires of the individual student. Satisfactory progress toward the degree is also judged by the Special Committee rather than by any arbitrary standards imposed by the Graduate School.

The Special Committee under which a Master of Arts or a Master of

Science candidate carries on his work is composed of a chairman who represents the major subject, and one representative of an appropriate minor subject. The Special Committee of a doctoral student is composed of a chairman, representing the major subject, and two other members representing other areas of interest. The chairman of the Special Committee directs the student's thesis research. Some Fields of study require two minor subjects for doctoral programs while for others only one is needed, but all Ph.D. Special Committees have three members.

The selection of the Field and the major subject, as well as the chairman of the Special Committee, is made by the incoming student. It is the privilege of the graduate student to ask any member of the Graduate School Faculty who is in the Field of his major subject to serve as his chairman. The chairman in turn advises the student about minor subjects and faculty members who might be appropriate to represent them on his Special Committee. The choice of major and minor subjects and the formation of the Special Committee must be recorded in the Graduate School Office within two weeks of the beginning of the first term of residency. However, since the student may be uncertain of his aspirations at that time, he is encouraged to change the membership of his Special Committee as his aims become more definite.

In some of the larger Fields of the Graduate School the difficulty in making a wise selection of a Committee is so great that the Field Representative or other faculty member may serve temporarily as the chairman of the Special Committee while the student seeks a permanent chairman and committee to supervise his programs of study.

The members of the Special Committee decide upon the student's program of study and research and whether he is making satisfactory progress toward the degree. They conduct and report on oral examinations, and they approve the thesis. The Committee and the student constitute an independent working unit. All members of the Graduate School Faculty, however, are free to participate in the scheduled examinations and review the theses of candidates for degrees.

The organization of the Graduate School at Cornell is based on a concept of Fields of study which is independent of colleges and departments. It is thus possible for a graduate student to take courses in any division of the University and to choose major and minor subjects without regard to organizational lines.

EXAMINATIONS

The Special Committee conducts the examinations that are required for the degree. At the discretion of the Special Committee these examinations may be entirely oral or both oral and written. The following examinations are required:

For the Master's degree: a final examination, which under certain conditions may be combined with the Admission to (Ph.D.) Candidacy Examination.

For the doctoral degrees: (1) A comprehensive Admission to Candidacy Examination for formal admission to doctoral candidacy. This examination may not be taken until two units of residence credit have been accumulated and is normally taken in the second or third year. Two terms of residence must be credited after this examination. (2) A Final Examination, which is primarily concerned with the doctoral dissertation.

In some Fields a qualifying examination is given at an early date to determine the student's fitness for undertaking advanced study and to enable the Special Committee to plan a program which will make him familiar with the requisite knowledge and techniques of his chosen field of study.

When the candidate has completed the thesis, he presents it to the Special Committee at the final thesis examination. This examination is oral and covers subject matter related to the thesis topic.

FOREIGN LANGUAGE REQUIREMENTS

Each Field of instruction has its own foreign language requirements which it considers most useful to the particular area of study. Any Special Committee may, at its discretion, require knowledge of foreign languages beyond the announced requirements.

Candidates required by Fields to demonstrate a reading ability in French, German, or Russian must pass the Graduate School Foreign Language Test given by the Educational Testing Service, Princeton N.J. 08540, and administered by the Graduate School. A charge is made to cover the cost of administering each test. As an alternative, candidates may pass the reading part of the CEEB college language test with a score satisfactory to the Division of Modern Languages. Students who take examinations in languages other than French, German or Russian, or in a speaking knowledge of any language, should arrange with the Graduate School Office for assignment to a suitable examiner. Arrangements to demonstrate a higher level of proficiency in a foreign language as required by some Fields may be made at the Graduate School Office.

A student may petition the Dean to transfer a language examination taken elsewhere to his record at Cornell.

Courses designed to aid graduate students in learning how to read French, German, and Russian are given by the Division of Modern Languages in cooperation with the Graduate School Faculty. There are two courses offered each term — one at the elementary and one at the intermediate level — in each of the languages. Anyone registering for them is expected to attend regularly throughout the term, take all examinations, and complete assigned work.

ELEMENTARY FRENCH, GERMAN, or RUSSIAN 151. Three hours. M W F (time to be announced).

INTERMEDIATE FRENCH, GERMAN, or RUSSIAN 152. Three hours. M W F (time to be announced).

THESIS

Candidates for the degrees of Master of Arts or Master of Science are required to submit a thesis in fulfillment of the requirements for the degree. In some fields a thesis is also required for professional Masters' degrees. Candidates for the doctoral degree must complete a thesis which constitutes an imaginative contribution to knowledge. The faculty requires publication of Ph.D. theses by abstract or microfilm.

RESIDENCE

The Graduate Faculty regards study in residence as essential. Although a person working off-campus may attain proficiency in a technique or even in a field of knowledge, he may fail in other ways to attain the breadth of knowledge necessary for scholarly work. In addition to contact with the libraries and physical facilities of the University, he needs the daily acquaintance, company, aid, and stimulus of others engaged in similar pursuits. He should form the habit of attending lectures, seminars, and meetings of groups in whose activities he takes interest.

Full-time study for one semester with satisfactory accomplishment constitutes one residence unit. The Graduate School Faculty requires that each candidate for a Master's degree earn two units of residence, and for the Ph.D. degree six units of residence. However, the time required to obtain the degree generally exceeds those minimum requirements.

A student must complete all the requirements for the Master's degree in four years and for a doctoral degree in seven years.

A student in a doctoral program may earn no more than two units for work done in Summer Research, Summer Session, and the Division of Extramural Courses. At least four of the six required units must be earned as a full-time student, earning three-quarters of a residence unit or more each term, and two of the last four units must be earned in successive terms of full-time study on the Cornell campus.

Transfer of Residence

Candidates for the Master's degree may not count study in other graduate schools as part of their residence. Candidates for the doctorate may be permitted to count study for the Master's degree as equivalent to two residence units; those who have received training of an exceptional quality and amount may petition for more. No commitment regarding this may be made until after the student has entered into residence and his Special Committee has had further opportunity to judge his accomplishments. The residence transferred must not exceed that which would have been earned under similar circumstances at Cornell. Credits secured during study as an undergraduate or as a special student, even

for work in courses designed primarily or wholly for graduate students, will not be allowed.

Summer Session

To receive residence credit through registration in the Summer Session, the candidate must register in both the Summer Session and the Graduate School and must file a statement of courses satisfactory to his Special Committee. The completion of eight or more hours of credit in the eight-week session, or a minimum of six hours in the six-week session, will count as one-half or two-fifths of a residence unit respectively, if approved in advance and reported as acceptable by the candidate's Special Committee.

Requirements for Masters' degrees may, upon approval of the appropriate graduate Field, be completed solely during the summer period if instruction in the chosen major and minor subjects is offered. Only two residence units for study in the Summer Session may be accepted in fulfillment of requirements for the doctorate. Upon recommendation by the Special Committee of a student and on approval by the Dean of the Graduate School, residence may be transferred for study done in one preceding Cornell Summer Session period if such study is attested to be an integral part of the graduate program subsequently undertaken.

SUMMER RESEARCH

To encourage students to continue their studies during the summer period, no tuition or fees are charged for summer research if the student has been registered during the previous academic year. Substantial funds are also available for summer fellowship and research assistantship support. A special summer fellowship program is also available for those students who have held teaching fellowship appointments during the previous academic year. Students have access to the regular services of the University Clinic and Hospital during the summer without charge.

Under certain conditions, students may also accumulate residence credit in the summer term.

Part-Time Studies

Essentially, all graduate students at Cornell are full-time students. In those cases where employment is necessary, students may hold positions requiring up to ten hours of work without reduction of residence credit. Teaching fellows and research assistants whose duties require up to twenty hours a week are able to obtain full residence credit.

The legislation with respect to eligibility of part-time employees for residence units is as follows.

Employment	Residence Units Allowable per Semester		
Total clock hrs. per week	*Contributory in the major field of study and on campus*	*Noncontributory but on campus*	*Off campus*
0–10 hours	1 unit	1 unit	1 unit
11–20 hours	1 unit	¾ unit	¾ unit
21–30 hours	¾ unit	½ unit	*(See paragraph below)*

If the employment is more than twenty clock-hours per week and is off campus, or if it is more than thirty clock-hours per week under any circumstances, a maximum of two-fifths of a residence unit per semester may be earned through registration in the Division of Extramural Courses, but this will be permitted only on the basis of petition approved prior to the time that the work is undertaken. For the degree of Master of Arts or Master of Science a maximum of one unit, and for the degree of Ph.D. a maximum of two units of residence may be earned in this way.

Therefore, under the circumstances described above, degree candidates may accumulate residence units for course work completed through the Division of Extramural Courses. Instruction is offered in certain fields of study both on and off the campus. Fifteen credit hours are the equivalent of one residence unit, and six credit hours the equivalent of two-fifths of a residence unit – the smallest fraction that will be recorded by the Graduate School toward fulfillment of residence requirements. Detailed information concerning extramural courses and registration procedures may be obtained from the Division of Extramural Courses, B-20 Ives Hall.

FINANCIAL SUPPORT

Extensive financial support is available to Cornell graduate students. Approximately 3,000 of the 3,300 graduate students have financial support in the form of fellowships, teaching fellowships, and research assistantships.

Since the requirements of graduate study are so great, students are discouraged from trying to obtain financial support through employment outside their academic interests.

No special forms are available for financial aid. The applicant should check the type or types of appointment for which he wishes to be considered on the application for admission form.

TEACHING FELLOWSHIPS

The duties of a teaching fellow normally involve classroom and laboratory instruction of undergraduates and, as such, play a major role in the educational process and the academic atmosphere of the University. Since a large majority of Cornell's graduate students eventually seek a career in teaching, the experience gained from these appointments is an invaluable part of the student's development. In most Fields of study students are encouraged to spend some time in teaching, and in a few Fields the faculty believe the experience so important that they require it of all students in doctoral programs. An appointment as a teaching fellow is usually in the student's major field or in one that is closely related. The duties require from ten to twenty total clock-hours a week of the student's time, depending on the Field. A teaching fellow whose duties are in his major Field of interest and do not exceed twenty hours is eligible for full residence credit. The remuneration varies widely, but it is usually from $1,900 to $2,700 for an academic year and may be supplemented by a scholarship which covers tuition and fees. A special summer fellowship program is also available for teaching fellows. Because of possible problems in communication with undergraduates, applicants from non-English speaking countries are not normally appointed as teaching fellows in their first year at Cornell. Appointments are made by department chairmen. Applications for these positions should be made to the Field Representative of the Field of the major study chosen.

RESEARCH ASSISTANTS

The duties of a research assistant involve work on a research project. The work performed is frequently applicable to the student's thesis research and is under the direction of the chairman of his Special Committee. The student is required to spend twenty hours a week, but if the research is in the field of his major interest he is able to acquire full-time residence credit. In many Fields of study such appointments are not normally made to students in their first year of graduate study.

FELLOWSHIPS

A fellowship ordinarily is awarded in open competition to a full-time student who is a candidate for a higher degree. The award is made as a tax-exempt gift, and it covers not only tuition and fees but may also provide a substantial stipend for living expenses during tenure. A student who holds a fellowship is free to select his own research project, and his primary responsibility is to pursue his studies for his degree. The award of the fellowship does not obligate the holder to render services to the University, except that in certain fields some teaching

is required of all graduate students for the sake of the experience and training, nor is the holder of a fellowship committed in any way in respect to future employment. The holder of a fellowship may accept no other appointment or employment without permission of the Fellowship Board; however, teaching responsibilities will usually be approved as a routine matter if they contribute to the student's graduate program and do not exceed ten clock-hours of work per week.

Fellowships are awarded primarily on the basis of scholastic ability and promise of achievement as a graduate student.

The number of academic year fellowships awarded by the Graduate School is so extensive that it is impractical to present a listing. (See also Summer Fellowship Support, page 17.) Many other fellowships are offered to students majoring in certain Fields of study, and some of these are noted in the descriptions of the Fields.

A new program has been initiated at Cornell for students in the Humanities and in selected Fields of the Social Sciences (Anthropology, Economics, Government, Linguistics, Psychology, and Sociology). Its aim is to reduce the time required for a Ph.D. degree. This is to be accomplished through a greatly enlarged program of support, without any sacrifice in the academic standards or requirements for the degree. Incoming students in the Fields covered by the program will be guaranteed support for four full years, including the summers following the first academic year. In most cases, there will be fellowship support for three of the years, with increasing stipends accompanied by full tuition and fees. One year, or in a few cases, up to two years, of teaching fellowship will provide both support and valuable experience and training. Dependency allowances will be available. About 90 percent of those in the program will be given modest summer scholarships to enable them to continue their studies throughout the year.

Many private and federally supported fellowships are also administered by the Graduate School. National Science Foundation and National Aeronautics and Space Administration Traineeships are available, as well as National Defense Education Act (NDEA) Title IV Fellowships. NDEA Fellowships offer three years of support to doctoral students who are U.S. citizens and who intend to enter a teaching career. (Since completion of a Ph.D. program at Cornell normally requires four years, and because the program is aimed at prospective teachers, NDEA Fellows are normally expected to gain teaching experience and have support during one of the years as teaching fellows.)

The purpose of the NDEA Title VI (NDFL) Fellowship program is to provide encouragement to individuals taking advanced training in languages and in associated area studies designated as being of critical importance to the United States. For area studies, see pages 28–38. Applicants who are interested in NDFL Fellowship support must so indicate when requesting their application materials for admission. National Institute of Health Traineeships are available and are offered by Fields which have been awarded such grants.

Prospective graduate students should also consider applying for fellowships awarded on a national basis by the National Science Foundation, the Atomic Energy Commission, the Public Health Service, the Woodrow Wilson National Fellowship Foundation, and the Ford Foundation. The deadlines for these programs are usually in the fall for the following academic year. In some cases it is possible for winners of NSF and AEC awards and PHS Fellows to hold half-time appointments as teaching fellows for an additional stipend.

New York State provides several forms of financial support. The Herbert H. Lehman Fellowship program is open to applicants from all states whose interest is in social sciences or public or international affairs. The Fellowships are awarded on a competitive basis and may be used only in New York State institutions. Lehman Fellowships provide each recipient with $4,000 for the first year of graduate study and $5,000 for each subsequent year. New York State residents are eligible for Regents College Teaching Fellowships or Regents Fellowships for Doctoral Study in Arts, Science, and Engineering. Any of these must be applied for in the fall on forms obtained from the Regents Examination and Scholarship Center, New York State Education Department, Albany, New York 12224.

New York State also grants every resident who applies and is certified to be a full-time student a Scholar Incentive Payment which may be, for graduate students, from $100 to $300 per term in the first year, and from $200 to $400 per term thereafter, depending on required tuition and income. However, the Scholar Incentive Payment may not exceed the amount that is $100 less than required tuition. Thus, in the state-supported divisions of Cornell University the minimum and maximum Scholar Incentive Payment is $100 a term in any year.

Because all state educational aid is expressly for the purpose of covering educational costs, every winner of a Cornell fellowship or scholarship covering tuition who also wins a state grant, or who is eligible to apply for a Scholar Incentive Payment, will have his Cornell award reduced by at least the amount of the minimum Scholar Incentive Program award.

A space is provided on the admission application form where the student may indicate the type of support for which he wishes to be considered. No special fellowship application form is required.

As agreed upon by some of the members of the Council of Graduate Schools in the United States, the regular time for notification of award from Cornell of fellowships and scholarships for the succeeding academic years is April 1. *All fellowship and scholarship applications received by February 1 will be considered for April awards,* and each applicant approved for award will be notified not later than April 6 as to whether he has a fellowship or is named as an alternate. It is hoped that the awardees will notify the Graduate School no later than April 15 of their acceptance or rejection of the award. Failure to do this by April 22 will be considered a declination. Applications received after February 1 may be considered only if vacancies occur.

SUPPORT IN THE HUMANITIES

Recognizing that the availability of financial support for continuing graduate students in the area of the Humanities is less than in other areas, Cornell has made a particular effort to compensate for this inequity by a special Cornell-supported program. Students in doctoral programs in the Humanities area who enter with financial support from Cornell, or with nationally awarded fellowships, are guaranteed support in the form of an assistantship or a fellowship for a four-year period, provided they are making satisfactory progress toward the doctoral degree.

SUMMER FELLOWSHIP SUPPORT

The Graduate School Faculty believes that graduate education, in contrast to undergraduate programs, should be on a year-round basis to enable students to obtain their degrees in a reasonable period of time. The majority of Cornell Ph.D. students are, therefore, supported over the summer period through research assistantships and fellowships. Normally the summer period is devoted to informal study and research rather than to course work, and no tuition or fees are charged.

Two extensive summer fellowship programs based on financial need are noteworthy. One involves awards to those students who have been full-time teaching fellows. The other involves fellowship support to students who are in the final stages of their thesis preparation. It is expected that some 200 summer fellowships will be awarded for the summer of 1968 under these two programs. Another 1,300 students will be supported as research assistants, and 250 students will be on twelve-month fellowships.

RESIDENCE HALL ASSISTANTSHIPS

Assistantships in University residence halls are available for men and women graduate students in any academic field. They are most appropriate for graduate students who desire experience in working with undergraduate students and University staff while contributing financially to their own study.

In the women's area one-third of the fifteen assistantships available are reserved for graduate students in the field of Student Personnel Administration. Ten assistantships, offering living expenses and a yearly stipend, are available to graduate women in other disciplines. Particulars and application forms may be obtained by writing to the Office of the Dean of Students, 133 Day Hall.

In the men's housing area there are three types of positions, all requiring a personal interview. There are a number of counselor positions available to single undergraduate and graduate men. Each counselor is responsible for a floor containing fifty-five freshmen. Counselor positions

carry free room for the first year and a $200 stipend in the second. The eight head resident positions are open to married graduate students without children. Each head resident is responsible for a dormitory of 250 men and five staff. The head resident lives in a two-room apartment and receives a $700 stipend.

Applications should be addressed to the Office of the Dean of Students, 133 Day Hall. The deadline for application for positions in men's dormitories is February 1.

LOANS

Only graduate students duly registered in a degree-granting program are eligible for loans. This does not include provisional or noncandidate students.

Cornell utilizes university, state, and National Defense Loan programs. The total amount of loan recommended, regardless of source, is based upon the financial need of the student as analyzed by the University Committee on Financial Aid.

Applications are available at the Office of Scholarships and Financial Aid, 105 Day Hall. State loan applications may also be obtained at this office.

PART-TIME EMPLOYMENT

Additional opportunities for part-time work are often available in connection with departmental research projects or other activities. Applications for this type of work should be made directly to the department concerned. If a candidate is employed in research or other work closely allied to his academic interest, he may find such employment academically valuable.

Progress in candidacy is difficult when a student attempts to support himself wholly or partially by work unrelated to his studies. It usually is sounder economy to borrow from the Office of Scholarships and Financial Aid and keep employment to a minimum. However, the University maintains a part-time student employment service in that office.

EMPLOYMENT OPPORTUNITIES FOR WIVES OF GRADUATE STUDENTS

Cornell University offers many nonacademic positions for working wives through the Personnel Division, B-12 Ives Hall. Types of work include secretarial and clerical work, work for technicians in the various laboratories, library work, limited nursing positions, and some administrative positions. Applications may be made through the Personnel Division upon arrival on campus. Applicants for academic positions should apply to the specific departments in which they are interested.

In addition to the University positions, the Ithaca area offers opportunities for similar positions in small industrial plants, Ithaca College, the local hospital, and various businesses, as well as for teaching positions in the public school system and some professional positions in service agencies. Applicants should go to the New York State Employment Office for further information regarding these opportunities.

GENERAL INFORMATION

ACTIVITIES FOR GRADUATE STUDENTS

Cornell is in a small academic town in central New York State. It has the advantages of a small-town atmosphere but at the same time has many cultural aspects that rival those of any large city. A significant concert program brings internationally famous artists to Ithaca. Dramatic programs, talks by visiting lecturers, and art exhibitions fill the weekly calendar of the University and present such a wide choice of events that a student cannot possibly attend all in which he is interested.

There are places for graduate students in many extracurricular activities shared by undergraduates; among others are intramural sports, drama, Glee Club, Sage Chapel Choir, publications, music, and folk dancing. A Graduate Student Activities Committee is active in scheduling weekly social events. A Graduate Wives' Club has had a long tradition of activity for the wives of graduate students. Willard Straight Hall and the Sage Graduate Center provide facilities for graduate groups and aid in planning special functions for them.

Cornell United Religious Work (CURW) includes a range of activities for graduate students. Its offices are in Anabel Taylor Hall, which serves as a headquarters for chaplains who represent several denominations and who may be consulted by students.

Cornell's location in the Finger Lakes Region of New York State stimulates outdoor activity. Many swimming and boating facilities are available. In addition, Cornell operates a private eighteen-hole golf course; indoor and outdoor swimming pools; and indoor skating rink; tennis, handball, and squash courts; gymnasium; and riding stables, all of which are open to graduate students. A variety of ski resorts also operate near by.

Almost all Fields of study sponsor weekly seminars for their faculty and graduate students.

COUNSELING

The University maintains a variety of counseling services available to graduate students. A student's primary academic counselors are the members of his Special Committee.

Other counselors who are able to help in matters of various kinds will be found in the Office of the Dean of Students, the Office of Scholarships and Financial Aid, the International Student Office, the Gannett Medical Clinic, and the Sage Graduate Center.

INTERNATIONAL STUDENTS

Cornell has, since its founding, welcomed students from abroad. Currently 1,107 foreign students representing 84 countries are pursuing study in a variety of Fields.

In addition, each year over one hundred faculty members spend some time abroad in study and research, often in close association with foreign universities. This creates within the University community opportunities for scholars from other countries to meet and exchange ideas with members of the Cornell faculty, who often have first-hand knowledge of several countries and understand and appreciate a variety of cultures.

Special study programs within the Graduate School permit study in depth of particular areas such as Africa, Asia, Southeast Asia, Latin America, and the Near East. Students from those areas have an opportunity to contribute to such programs.

The Ithaca community is in a natural setting which allows for enjoyment of many recreational activities. In addition, varied cultural and intellectual activities are sponsored by the University. Tours of the community are conducted at the beginning of the fall semester. A group of Cornell faculty and Ithaca families maintain a Host Family Program, in which foreign students are invited to share in some aspects of American family life in the Ithaca community. With the University population a varied one, the community itself, although not large, tends to have a more cosmopolitan atmosphere than most other small cities, and the student can usually find an outlet for a wide variety of interests.

The University maintains an International Student Office at 142 Day Hall. Students from abroad are invited to consult the staff of that office on any questions they may have. The office works in close association with academic advisers and sponsors, and also with persons involved in a number of student and community programs in efforts to enrich the international and cultural life of Cornell. Students are asked to report to this office upon arriving in Ithaca.

HEALTH REQUIREMENTS ON ENTRANCE

The following health requirements for entering graduate students have been adopted by the Board of Trustees of Cornell University. Failure to fulfill these requirements may result in loss of privilege of registering the following term. The responsibility for fulfilling these requirements rests upon the student.

IMMUNIZATION. A satisfactory certificate of immunization against smallpox, on the form supplied by the University, must be submitted

before registration. It will be accepted as satisfactory only if it certifies that within the last three years a successful vaccination has been performed. If this requirement cannot be fulfilled by the student's home physician, opportunity for immunization will be offered by the Cornell medical staff during the student's first semester, with the cost to be borne by the student. If a student has been absent from the University for more than three years, immunity will be considered to have lapsed and a certificate of revaccination must be submitted.

It is strongly recommended by the University Health Services that all graduate students have immunization against tetanus before entering the University. All graduate students may, however, obtain initial and all booster tetanus toxoid immunizations at the Gannett Clinic for a nominal charge.

HEALTH HISTORY. Students accepted for admission will be required to submit health histories on forms supplied by the University.

X RAY. Every student is required to have a chest x ray. Opportunity is given to satisfy this requirement during the student's first week on campus. The cost of the x ray examination is included in the General Fee. When a student who has been away from the university for more than a year wishes to re-enter, he must at his own expense, once more fulfill the chest x ray requirement, and he must also submit a new health history.

HEALTH SERVICES AND MEDICAL CARE

Health services and medical care for students are centered in two Cornell facilities: The Gannett Medical Clinic (outpatient department) and the Sage Hospital.

Students are entitled to unlimited visits at the Clinic. Appointments with individual doctors at the Clinic may be made by calling or coming in person. (An acutely ill student will be seen promptly whether he has an appointment or not.) Students are also entitled to laboratory and x ray examinations indicated for diagnosis and treatment, hospitalization in the Sage Hospital with medical care for a maximum of fourteen days each term, and emergency surgical care.

If a student requires medical attention when the Clinic is not open, an attending physician or emergency service is available at Sage Hospital. The cost of these services is covered in the General Fee.

On a voluntary basis, insurance is available to supplement the services provided by the General Fee. For further details see the *Announcement of General Information*. If, in the opinion of the University authorities, the student's health makes it unwise for him to remain in the University, he may be required to withdraw.

If a student prefers to consult a private physician rather than go to the Clinic, or to have the services of a private doctor while a patient in Sage Hospital, he must bear the cost of these services.

LIVING ARRANGEMENTS

DORMITORY ACCOMMODATIONS. The University has established Sage Hall as a graduate residential center. Its dormitory facilities accommodate approximately 100 men in the north side of the building and 105 women in the south side. The Graduate Center, which is available for use by all graduate students and faculty, also contains a cafeteria seating 200, study rooms, and lounges. In addition, Cascadilla Hall has been remodeled to accommodate approximately 160 single graduate men.

Applications for dormitory accommodations may be obtained any time after January 1 for the coming academic year by writing the Department of Housing and Dining Services, 223 Day Hall.

FAMILY ACCOMMODATIONS. The University, through the Department of Housing and Dining Services, has three apartment developments for married students and their families. They are Cornell Quarters, Pleasant Grove Apartments, and Hasbrouck Apartments, with total housing for about 400 families. All apartments are unfurnished. For further information and application, write the Department of Housing and Dining Services, Room 223, Day Hall.

OFF-CAMPUS HOUSING. Because it is required that all students live in Cornell-approved housing, an office listing off-campus housing facilities is maintained by the Department of Housing and Dining Services in Room 223, Edmund Ezra Day Hall. It functions as a bureau of information, maintaining files of voluntarily listed accommodations for use of students and staff members who call at the office. Because the list of available accommodations is constantly changing, it is not practical to mail listings, nor is it feasible to maintain a waiting list of persons seeking accommodations.

MOTOR VEHICLES

The University does not encourage student use of motor vehicles but recognizes that in certain cases there may be important reasons why a student needs a motor vehicle. University regulations apply to all types of motor vehicles, including automobiles, motorcycles, motor bikes, and motor scooters.

Every student who owns, maintains, or for his own benefit operates a motor vehicle in Tompkins County, during the time the University is in session, must register such vehicle with the Safety Division Office, even though the vehicle may be also registered by faculty, officers, or employees. All students must register motor vehicles within the prescribed time for University registration at the beginning of the fall term (*exception:* students who are not then subject to this rule but later become subject to it must register vehicles within five days after becoming so subject). Students entering the University for the spring semester or re-entering after a period of absence must register motor

vehicles with the Safety Division at the time of, or within the time for, general registration.

Every student who has a motor vehicle must comply with the following requirements: (1) the student must be legally qualified to operate a motor vehicle in New York State; (2) the vehicle must be registered in New York State or legally qualified to be operated on the highways of New York State; (3) the vehicle must be effectively insured against public liability for personal injury and property damage for the minimum of $10,000 – $20,000 – $5,000, for the duration of such registration and while the vehicle is under the control of the registering student; (4) the registration fee covering the fall and spring terms, or any part thereof, is $4 and is due and payable in the Treasurer's Office on the same date as tuition and other fees; in case of late registrants, the fee will be due within a week after such registration. A fine is levied if the vehicle is not registered within the specified time.

No student may park his motor vehicle on the campus from 8 A.M. to 5 P.M. Monday through Friday, or from 8 A.M. to 1 P.M. Saturdays. Certain areas are restricted twenty-four hours a day; such areas include "no parking" zones, dormitory parking areas, and areas listed as limited at all times to holders of specific permits.

Special area parking permits are issued only after careful consideration by the Safety Division Office. Extenuating circumstances (physical disabilities, etc.) are the basis for the issuance of these permits.

The student's registration in the University is held to constitute an agreement on his part that he will abide by all its rules and regulations with regard to traffic and parking or suffer the penalty prescribed for any violation of them.

Correspondence regarding motor vehicles should be addressed to the Board on Traffic Control, G-2 Barton Hall.

PLACEMENT

The University Placement Service, 122 Day Hall, assists Cornell men and women who are ready for positions in business, industry, government, and other institutions by supervising the assembling and presentation of personnel records and making arrangements for on- and off-campus interviews. Graduate students are advised to register with the office approximately a year before they will be available for employment.

The Educational Placement Service, 320 Wait Avenue, performs a similar function for those whose vocation is teaching. Many of the professional schools and colleges maintain separate placement offices for the special professions; their services are available to registered graduate students and alumni.

TUITION AND FEES

Tuition and fees* become due when the student registers. Any student who fails to pay his tuition, fees, and other indebtedness to the University at the Treasurer's Office within the prescribed period of grace will be dropped from the University unless the Treasurer has granted him an extension of time to complete payment. The Treasurer is permitted to grant such an extension when, in his judgment, the circumstances of a particular case warrant his doing so. For any such extension the student is charged a fee of $5. A reinstatement fee of $10 is assessed against any student who is permitted to continue or return to classes after being dropped from the University for default in payments. The assessment may be waived in any instance for reasons satisfactory to the Treasurer and the Registrar when such reasons are set forth in a written statement.

Students registering at any time during the last ten weeks of any term are required to pay tuition at the rate of 10 per cent of the regular tuition of the term for each week or fraction of a week between the day of registration and the last examination day of the term.

Tuition or fees may be changed by the Trustees at any time without previous notice.

FEES PAYABLE BY GRADUATE STUDENTS

Registration Deposit

A deposit of $28 must be made by every applicant for admission after the applicant has received notice of acceptance, unless the candidate has previously matriculated as a student at Cornell University. This deposit is used at the time of first registration to pay the matriculation fee, chest x ray, and examination-book charge, and covers certain expenses incidental to graduation if the student receives a degree. The deposit will not be refunded to any candidate who withdraws his application after May 22 or after twenty days of his admission approval. This fee is *not* covered by university fellowships, scholarships, or assistantships.

Tuition

Tuition is $200 a term for all students registered in the Graduate School whose major chairman is on the faculty of the statutory divisions† of the University. Those with major work in the School of Nutrition also pay $200 a term. Tuition in the Field of Education is generally $200 except in a few cases, where it is $772.50. All students in other divisions

* All statements in this section are prepared by the Treasurer, who alone is authorized to interpret them.

† The statutory divisions are the Veterinary College, the Colleges of Agriculture and Home Economics, and the School of Industrial and Labor Relations.

must pay tuition of $772.50 a term. Tuition is payable at the beginning of each term.

Upon recommendation by the appropriate college dean and by action of the Controller, for each appointment in a statutory school or college, waiver of tuition in the Graduate School may be made to a member of the teaching or scientific staff, whose major field of study is in a statutory school or college.

Assistants in statutory schools or colleges who are on twelve-month appointments and who are registered for Summer Research for credit in the Graduate School may be recommended for waiver of tuition during the summer period under the above limitations. This waiver of tuition does not apply if the student registers in the Summer Session or is not doing productive work for the department.

Any student who is to receive less than full residence credit because of his employment should apply for proration of tuition on forms procurable at the Graduate School Office. *Tuition is based on residence eligibility.* See pages 11, 13.

General Fee

A fee of $275.00, payable at the beginning of each term, is required of each student registered in the Graduate School whose major chairman is on the faculty of one of the statutory divisions,* or on the faculty of the School of Nutrition, or (in most cases) of the School of Education. All others pay a fee of $252.50. This General Fee contributes toward the services supplied by the libraries, Clinic and Hospital, and the student union in Willard Straight Hall, and pays a portion of the extra cost of laboratory courses and general administration.

A student who is regularly registered in the Graduate School for either one or both terms of the academic year and has paid the above fee is entitled to these services while in residence during the summer immediately following the academic year without payment of an additional General Fee. If such a student registers with the University during the summer, he is liable for payment of any tuition and other fees, and must present his ID card at the time of payment of these charges in order to claim exemption from payment of the General Fee.

A graduate student who returns to the University to present his thesis and to take the final examination for an advanced degree, all other work for that degree having been previously completed, must register as a "Candidate for Degree Only" and pay a fee of $35.

Other Fees

THESIS FEE. Each doctoral candidate must pay $30 at the time of depositing the approved thesis and abstract in final form. This fee

* The statutory divisions are the Veterinary College, the Colleges of Agriculture and Home Economics, and the School of Industrial and Labor Relations.

covers the cost of preparing a master microfilm of the entire thesis; of publishing the abstract in the bimonthly periodical, *Dissertation Abstracts;* of mailing the microfilm and abstract to the microfilm publisher; and of binding both copies of the thesis for deposit in the University Library.

LIMITED REFUNDS. Part of the tuition and General Fee will be refunded to students who officially withdraw or take a leave of absence during the first nine weeks of a term. A student arranges for a leave of absence or withdrawal at the Graduate School Office. Students who withdraw are charged tuition and the General Fee at the rate of 10 per cent for each week or fraction of a week from registration to the effective date of withdrawal. No charge is made if the student withdraws within six days of registration. No part of the registration or matriculation fee is refundable.

SUMMER SESSION. Graduate students who attend classes in the Summer Session must register both in the Graduate School and in the Summer Session; they must pay the tuition and fees listed in the *Announcement of the Summer Session.*

SUMMER RESEARCH. Students registered for Summer Research pay one half of the General Fee for a registration period of not more than eight weeks and the full fee for a registration period of over eight weeks unless they were regularly registered in the Graduate School during the previous academic year. For those students eligible for and desiring residence, a prorated tuition is charged in accordance with the fraction of a residence unit to be earned, based on the tuition in effect for the subsequent academic term.

IN ABSENTIA. A graduate student registered *in absentia* will pay a fee of $35 each term.

SPECIAL RESOURCES FOR RESEARCH AND ADVANCED STUDY

The descriptions below are limited to major general facilities at the service of graduate students in any of a variety of fields of instruction. In addition, substantial collections and facilities, in many instances unique, have been assembled for the use of graduate students. Although the facilities cannot be described adequately in this Announcement, some of them are mentioned in the statements given under the Fields of Instruction on pages 48–175.

CORNELL UNIVERSITY LIBRARIES

The libraries are among the principal facilities in the University's program of graduate studies. The total number of volumes at Cornell is now over 3,000,000, and that figure increases by about 175,000 each

year. For the convenience of students and faculty, the holdings are organized into a controlled system of distinct libraries. Some of the libraries are large; some have limited holdings. Some are general, some selective. Each library, whether within one of the colleges or housed in a building of its own, is situated where its books and its facilities lie most easily available to those who use them most. The libraries, whatever their nature, have been developed over many years by scholarly librarians and professors with the view of achieving breadth and depth in the central libraries, utility and coherence in the specialized ones.

The University's libraries offer support for graduate studies at several levels. They provide basic readings in virtually all subjects, collateral studies for classroom and seminar instruction, and highly specialized materials for advanced students. An unusually rich collection of reference works, both modern and antiquarian, expedites both the daily study and dissertational research. Of journals and periodicals, about 35,000 titles are available, most of them in complete runs, some of them in multiple copies, all of them immediately available. Special departments are maintained for maps, microtexts, documents, newspapers and other such collections.

To most graduate students, Olin Libarary, designed primarily as a research library, becomes the most familiar. Olin Library, completed in 1961, offers every modern library facility for its readers. The building is completely air-conditioned, scientifically lighted, comfortably furnished, and organized for efficient operation. It provides easy access to the book stacks, convenient photocopying facilities, and a comfortable lounge area for graduate students. Congestion is reduced not only because of architectural design but also because undergraduates have their own open-stack library in a separate building. A graduate student whose work has advanced to the writing stage may apply for use of a carrel adjoining the book stacks in order to facilitate completion of his dissertation. Olin Library is open in term time from 8 A.M. to 11:30 P.M. weekdays and from 1 P.M. to 11:30 P.M. Sundays.

Within Olin are a number of special collections likely to be of particular interest to advanced students of the social sciences and the humanities. The Department of Rare Books houses several distinguished collections, among them books and manuscripts relating to Dante, Petrarch, Wordsworth, Joyce, Shaw, and other literary figures. The Noyes collection is rich in American historical documents, especially those pertaining to Lincoln and the Civil War. Students in the social sciences will also find extraordinarily interesting manuscripts and books in the collections of slavery and abolition, of witchcraft, of the French Revolution, and of the life and times of Lafayette. Long familiar to professional scholars are the Wason Collection on China and the Chinese, Japan, and Southeast Asia collections, and also the Old Icelandic Collection. The History of Science collections include the Adelmann library of embryology and anatomy, and the library of the French scientist, Lavoisier. The collection of Regional History and Cornell University archives is a manuscript depository with total holdings of more than 14 million items. These manuscripts relate to all aspects of the economic, political, and social history of this region and the areas

historically connected with it. Here too are the documents and manuscripts relevant to the founding and development of Cornell University. In addition to the collections in Olin Library, many of the college and department libraries also contain materials unique in their respective fields. Curators and reference librarians in all the libraries are available for counsel concerning the availability and use of research materials.

The University libraries in aggregate consist of Olin Library, as mentioned, Uris Library for undergraduates, the Physical Sciences Library, the Mann Library of Agriculture and Home Economics, and the libraries of the following colleges and schools: Architecture and Fine Arts, Business and Public Administration, Engineering, Hotel Administration, Industrial and Labor Relations, Law, Medicine (in New York City), and Veterinary Medicine. Added to these are the libraries of academic divisions and departments, together with those of the Agricultural Experiment Station at Geneva, New York, and of the Cornell Aeronautical Laboratory at Buffalo.

INTERNATIONAL STUDIES PROGRAMS

Center for International Studies

The Center for International Studies has as its primary function the coordination and support of the international activities of Cornell University. In addition to its role as a link between the activities of the specialized programs, the Center endeavors to stimulate new research and development and to advise the University on contract commitments sponsored by government or private agencies. In addition, the Center brings to Cornell visiting faculty, postdoctoral research fellows, and distinguished academic and professional personnel in the area of international affairs. The Center for International Studies has no faculty, students, or curriculum of its own. Its research and other programs depend upon effective interaction with the faculty of the University's existing schools, colleges, and departments. The offices of the Center are located in Rand Hall.

The student interested in a particular foreign area or in particular international problems will often find that the faculty of his own major discipline includes specialists that provide appropriate instruction and academic guidance. For example, courses in the following fields, among others, are regularly offered under the relevant departments: comparative government, international relations, international law and organization, international and comparative labor relations, international economics and the economics of development, international agricultural development, international population problems, and foreign languages and literatures.

The student seeking specialized foreign area knowledge may focus on one of the following three major, broadly-based, interdisciplinary area programs: China Program, Latin American Studies, and Southeast Asia Program. In addition to these major area programs, it is pos-

sible for the student to pursue an area interest in African Studies, South Asia Program, or Soviet Studies.

The continued growth of these programs has been accompanied by the creation of an outstandingly comprehensive infrastructure of staff, library, language facilities, and other necessary resources.

Further information about the Center may be obtained from the Director, 216 Rand Hall.

African Studies

ADVISORY FACULTY COMMITTEE ON AFRICAN STUDIES: William H. Friedland, Chairman; Eqbal Ahmad, Douglas Ashford, Harold Feldman, Milton Konvitz, Chandler Morse, Stephen Muller, Thomas Poleman, Victor Turner, Frederick Tom, Mary Wood.

Cornell University has substantial facilities for graduate study and research on Africa. Many members of the faculty in a variety of fields are qualified by research experience in Africa to provide instruction or guidance to students who wish to specialize in some aspect of African studies, who plan to work there, or who are interested in a general or comparative knowledge of the area. Instruction and training in general linguistics are available for students expecting to deal with tribal peoples, and special courses on particular African languages (e.g., Ibo, Yoruba) have been given in recent years. Courses are regularly offered on the cultures and social systems of Africa and on the problems of economic, political and social development of the area. The University libraries provide a good working collection of books, documents, maps, newspapers, and periodicals on Africa of sufficient scope to enable students and staff to carry on regional research. A representative group of African students is attracted to Cornell each year, most of whom are eager to discuss African life and problems with interested students from other areas.

Inquiries should be directed to Professor William H. Friedland, Chairman, Committee on African Studies, Ives Hall.

China Program

FACULTY: Knight Biggerstaff, Nicholas C. Bodman, Nai-ruenn Chen, Chuen-tang Chow, John W. Lewis, Ta-chung Liu, John McCoy, David Mozingo, Charles A. Peterson, Harold Shadick, Judith M. Triestman, Arthur P. Wolf, Martie W. Young.

Maurice Freedman, Professor of Anthropology at the University of London, will conduct a seminar in the fall semester.

The China Program provides comprehensive graduate-level training and sponsors a wide range of research. The faculty represent the following fields: anthropology, economics, government, history, history of art, linguistics and literature.

Graduate students in the program take a major in one of the fields listed above. They are expected at an early stage to attain sufficient mastery of the Chinese language to permit use of Chinese sources in their courses and seminars and in their research.

The focus of much of the research and teaching in the Program is the society, polity, economy, culture, and arts of modern and contemporary China. Students with this concentration are also expected to develop a general knowledge of traditional institutions and culture. Students majoring in history concentrate on medieval or modern China; no chronological limits apply to those in the history of art, linguistics, or literature.

Several China Program fellowships are offered each year to first-year graduate students. They ordinarily carry stipends of $2,000 plus tuition and fees. Research assistantships are available from time to time. London-Cornell Studentships are open to advanced Ph.D. candidates in the social sciences and humanities who are in the China Program. They are tenable for study during an academic year at the London School of Economics and Political Science or at the School of Oriental and African Studies of the University of London. Stipends range up to $3,000 plus air fares and tuition and fees.

London-Cornell Field Research Grants are open to Ph.D. candidates in the social sciences and humanities who are in the China Program. They are tenable for up to 22 months for the purpose of dissertation research. London-Cornell Field Research grantees may conduct their field work in any part of East Asia where Chinese communities or materials on modern and contemporary China are accessible. Stipends range up to $12,000 for twenty-two months, including travel and research expenses.

National Defense Foreign Language fellowships and Foreign Area Training fellowships are tenable in the Program. Graduate students may also apply for other assistantships, fellowships, and scholarships offered by the University and by its departments.

Additional information on the Program and the various fellowships and awards may be obtained by writing to the Director, China Program, 103 Franklin Hall.

International Agricultural Development Program

Cornell University provides unusual scope and facilities for graduate-level study and research concerning development of the critical agricultural sector of newly developing nations. An integrated program of research and graduate training is available in the various biological, physical, and social sciences fields which are relevant to agricultural development. All fields of study in the New York State College of Agriculture at Cornell University have faculty members with intensive foreign experience and have students training for overseas work.

A student preparing for work in International Agricultural Develop-

ment majors in a specific Field. In addition to basic preparation in that Field, he will minor in the Field of International Agricultural Development. The student may follow courses which help him in applying his knowledge to the special conditions of newly developing nations, consult with experienced faculty members in regard to such application, and pursue a research project for his dissertation which is relevant to the special problems of newly developing countries. In much of this work the program in agriculture draws upon the strong international programs in other colleges of the University, including the area study programs and the varied offerings in modern languages.

Faculty experience in overseas work is continuously developed through work on College overseas programs, individual consulting assignments, and the ongoing research of faculty members and their students. The environment for the International Agricultural Development Program is further enhanced by more than 250 foreign graduate students majoring in the various Fields represented by the College of Agriculture.

Substantial expansion has recently taken place in the international program of the seven departments — agricultural economics, education, rural sociology, agronomy, animal science, plant breeding and plant pathology. In addition to many regular faculty members with extensive overseas experience, several members of these departments devote themselves full time to research and teaching in international agricultural development; they have built special programs of research and continuing contact with particular geographic areas. The departments have a number of assistantships and teaching fellowships designed to finance graduate students while they work closely with the teaching and research program in international agricultural development. Doctoral candidates in these departments who are interested in international agricultural development generally do field research in newly developing countries for their doctoral dissertations.

Similar expansion of international activities is under way in other subject matter areas of the College of Agriculture. At present, most departments in the College also have departmental assistantships and teaching fellowships which are open to outstanding students in those departments.

Additional information may be obtained by writing to Professor K. L. Turk, Director, International Agricultural Development Program, Roberts Hall.

International Legal Studies

The Cornell Law School offers a program of concentrated study in the international legal field. The full program is ordinarily pursued by LL.B. candidates in their second and third years of regular law study, but all courses in the field are open to graduate students in law. Some of these courses are offered by visiting faculty members who come to the Law School under its program for distinguished foreign professors. A number of foreign scholars and students also come to

Cornell for research and study in the comparative and international law fields. Other activities of the International Legal Studies Program have included faculty seminars in comparative law, summer conferences in public international law, and a program of speakers and seminars open to students. In addition, the Law School sponsors a small number of fellowships for foreign students to pursue graduate work in law.

For more detailed information, see the current *Announcement of the Law School,* the current *Annual Report of the Center for International Studies,* and the current issue of "International Studies at Cornell University – Courses of Instruction." Further information may be obtained by writing to Professor Robert A. Armstrong, Chairman, Graduate Study Committee, the Cornell Law School, or to the Director, Center for International Studies, 217 Rand Hall.

Latin American Program

FACULTY: Tom E. Davis, Director; Charles Ackerman, Frederick B. Agard, Solon Barraclough, Jerome S. Bernstein, Dalai Brenes, Frank Cancian, Martin Dominguez, Matthew Drosdoff, Charles L. Eastlack, Donald K. Freebairn, Rose K. Goldsen, Richard Graham, Eldon Kenworthy, Henry A. Landsberger, Thomas F. Lynch, Robert E. McDowell, James O. Morris, Thomas Poleman, Bernard Rosen, Donald F. Solá, J. Mayone Stycos, Terence S. Turner, William W. Whyte, Frank W. Young.

The Latin American Studies Program enables the graduate student to develop specialized competence in the history, culture, social organization, and language of Latin American countries. The student majoring in a relevant discipline can minor in Latin American Studies.

In addition to an interdisciplinary seminar, forty courses directly pertaining to Latin America are offered by the Departments of Agricultural Economics, Agronomy, Animal Science, Anthropology, Economics, Government, History, Housing and Design, Industrial and Labor Relations, Romance Studies, Rural Sociology, and Sociology. The courses constitute the basis for formulating programs leading to a graduate *minor* in Latin American Studies. Normally, five or six semester-long offerings satisfy the formal course requirements. In addition, the degree candidate minoring in Latin American Studies must exhibit proficiency in reading and speaking either Spanish or Portuguese.

Applications for scholarships, fellowships, or teaching fellowships should be made to the relevant departments. Ford Foundation support for the Program enables the University to award annually approximately ten fellowships providing an academic-year stipend of $2,250 to supplement an award of tuition and fees. The holders of the fellowships are designated Ford Foundation Fellows in Latin American Studies. Students minoring in Latin American Studies also qualify for Title VI N.D.E.A. Modern Language fellowships. Application forms may be obtained from the Graduate School.

Summer research travel grants are available to selected graduate students through the Latin American Studies Program, and to undergraduate and graduate students through the Cornell-Brazil Project.

Support for thesis research in Latin America may be obtained from the Foreign Area Training Fellowship Program, the Social Science Research Council, Fulbright-Hays, the Doherty Foundation, the Organization of American States, and Cornell University.

Because of the considerable volume of research on Latin America currently being carried out by Cornell faculty members, students will normally be afforded the opportunity of participating in ongoing projects while in residence and will generally be expected to do field work in Latin America at some stage of their graduate training. Major research projects are under way in the fields of Andean community development, comparative economic development, fertility and population, descriptive linguistics, and urbanization.

Additional information may be obtained by writing to Professor Tom E. Davis, Director, Latin American Program, Rand Hall.

Near Eastern Studies

ADVISORY FACULTY COMMITTEE ON NEAR EASTERN STUDY: Isaac Rabinowitz, Chairman; J Milton Cowan, A. Henry Detweiler, Alfred E. Kahn.

Students wishing to relate the work of their major or minor subjects to Near Eastern area or language studies should seek advice or information from the Faculty Committee on Near Eastern Studies. In a number of fields, the University's resources for specialized graduate study and research on countries of the Near East are of considerable value. Members of the Committee can provide suggestions regarding relevant courses in various subjects, assistance in planning research on the Near East, and guidance in applying for area training or research fellowships. Inquiries should be addressed to Professor Isaac Rabinowitz, Chairman, Department of Semitic Languages and Literatures, 173 Goldwin Smith Hall.

South Asia Program

(Bhutan, Ceylon, India, Nepal, Pakistan, Sikkim)

STAFF: Gerald Kelley, Director; Messrs. Leonard P. Adams, Eqbal Ahmad, Douglas E. Ashford, Harold R. Capener, Arch T. Dotson, Gordon H. Fairbanks, Harold Feldman, James Gair, Michael Hugo-Brunt, Kenneth A. R. Kennedy, John W. Mellor, Stanley J. O'Connor, Morris E. Opler, Robert A. Polson.

The increasing importance of the peoples of the Indian subcontinent and of the role they play in world affairs enhances the need for providing opportunities in America for training and research in the field of Indic studies. The South Asia Program at Cornell, dealing primarily with India, Pakistan, Ceylon, and Nepal, is organized and equipped to

help meet this need. Since 1948 it has sponsored a series of research projects on India and Ceylon, and it has trained a distinguished group of younger American and South Asian scholars in South Asian area and language studies. The Program faculty includes members from agricultural economics, anthropology, government, history of art, child development and family relationships, business and public administration, rural sociology, industrial and labor relations, city and regional planning, and languages and linguistics. Sanskrit, Pali, Hindi, Urdu, Telugu, and Sinhalese are languages regularly offered at Cornell. Arrangements may be made for the intensive study of other South Asian languages at summer institutes held on different American university campuses each year.

Qualified graduate students interested in specializing in the study of South Asia minor in Asian Studies with concentration on South Asia, in South Asian art history, or in South Asian linguistics. Advanced degree requirements for this minor are roughly comparable in terms of South Asian materials to those for the Southeast Asia concentrations given below. The doctoral candidate must have a reading knowledge of Hindi or, depending upon the subarea of his specialization, some other important language of South Asia.

RESEARCH AND FIELD TRAINING

The doctoral dissertations of students in the South Asia Program are normally based on research done in India, Pakistan, Ceylon, or Nepal. Students' field research may benefit from advice and guidance in the field by a program staff member. At least one member of the faculty of the South Asia Program has been in South Asia for each of the last several years. Cornell is a charter member of the American Institute of Indian Studies, which was organized to facilitate study and research in India by American advanced students and by faculty specializing in various aspects of Indian civilization and contemporary affairs. The University also maintains close links with a number of research agencies, programs, and institutions of higher learning, such as the Deccan College Linguistic Program and the Department of Linguistics, Delhi University. Staff members of these institutions have provided valuable assistance to Cornell students working in India. There are opportunities for graduate students to become associated with Cornell-sponsored research in South Asia or to carry on independent research abroad. Every effort is made by the Program staff to aid qualified students to obtain financial support for a field training or research project in one of the countries of the area.

Research interests under the South Asia Program are focused largely on recent or contemporary developmental problems of the countries of the area — on changes taking place in the economic, political, social, religious, artistic, and intellectual life of the region. A long-term research project in progress in India is primarily concerned with the ramifying problems of introducing technological changes and the influence of such changes when adopted. For this research program, faculty and students in anthropology have carried on, since 1949, an

extended and varied series of rural and urban community studies in several different regions of India from the Deccan into the Himalayan foothills. A major related project, the Cornell International Agricultural Development Program, which is supported by Ford Foundation funds, is concerned with the development of the entire agricultural sector of the Indian economy. With Ford Foundation support, Cornell is assisting Delhi University to become a major center in the field of linguistics. At the same time, other studies in urban renewal and regional planning, public administration, the role of government in cultural change, and recent movements in the arts and in religions and ideologies are in progress under faculty direction. Cornell is also making a special study of the Sinhalese language and of linguistic problems of Ceylon, a nation so far much neglected by American scholars. Research is also under way on Oriya and Telugu, important regional languages of India. The new nations of South Asia present so many problems for study that the areas of inquiry open to students and staff members are limited only by availability of research means.

FELLOWSHIPS AND ASSISTANTSHIPS

Fellowship and assistantship awards are available to qualified graduate students minoring in Asian Studies with a concentration on South Asia. The South Asia Program fellowships are open to incoming graduate students with South Asia interests. Stipends range up to $2,500 plus tuition and fees and should be applied for by writing to the Director, South Asia Program, 221 Morrill Hall. Students in the South Asia Program are also eligible for assistantships in their major discipline departments, for fellowships and scholarships offered by the Cornell Graduate School, for National Defense Foreign Language fellowships, and for Foreign Area Training fellowships. Additional information on financial aid may be obtained by writing to the Director, at the address given above.

Southeast Asia Program

FACULTY: Arch T. Dotson, John M. Echols, Frank H. Golay, Alexander B. Griswold, Robert B. Jones, Jr., George McT. Kahin, Stanley J. O'Connor, Robert A. Polson, Lauriston Sharp, James T. Siegel, John U. Wolff, O. W. Wolters.

The Southeast Asia Program possesses substantial facilities for study and research on the graduate level and provides exceptional opportunities for general or specialized work on all of Southeast Asia in various disciplines of the humanities, social sciences, and some natural sciences, as well as in interdisciplinary area seminars. Instruction in the major languages of the area is an integral part of the graduate training of the Southeast Asia Program. Much basic and pioneering research remains to be done in this area, and the Southeast Asia Program is organized and equipped to help meet such needs.

Special intensive instruction in Southeast Asian languages is avail-

able during summer sessions. Entering graduate students intending to study one of these languages are encouraged to begin such study during the summer preceding registration in the Graduate School. Inquiries should be made as early as possible to the Director of the Southeast Asia Program.

Southeast Asia Program fellowships are available on a competitive basis to graduate students. They carry stipends of up to $3,200 plus tuition and fees, and are available only to qualified candidates for advanced degrees at Cornell. Competition for these awards is open to citizens of the United States or Canada, nationals of Southeast Asian countries, and, in exceptional cases, nationals of other countries.

The fellowships are available to applicants who are able to demonstrate a serious scholarly interest in Southeast Asian studies; who show the greatest promise of becoming qualified regional experts with specialization in a relevant discipline of the humanities, social sciences, or certain natural sciences; and who are admitted to the Cornell Graduate School for advanced work in such a discipline. Previous experience in Southeast Asia or in the study of that area is not necessarily required. It is important that the applicant be able to show that advanced work in a major subject offered at Cornell, combined with work in the Southeast Asia Program, will make his future professional activities more effective; this requirement is particularly important for a student in the natural sciences.

Fellowships are normally awarded for one academic year. If the student's work during the first year has been of high caliber, reappointment is sometimes possible. In such cases, formal reapplication is expected from the student. The primary purpose of these awards is to encourage graduate students to acquire a substantial knowledge of Southeast Asia while majoring in one of the discipline Fields of the Graduate School. Accordingly, they are usually offered only to students who take a minor in Asian Studies and participate fully in the Southeast Asia Program. The recipient of a fellowship may be asked to devote up to six hours a week under faculty supervision to work connected with the Program.

London-Cornell Studentships are available for advanced Ph.D. candidates in the social sciences and in the humanities who have already had at least one year of resident study in the Southeast Asia Program. These fellowships are tenable for study during an academic year at the School of Economics and Political Science or the School of Oriental and African Studies in the University of London. Stipends range up to $3,000 plus air fares and tuition and fees. London-Cornell Field Research Grants are open to Southeast Asia Program Ph.D. candidates in the social sciences and humanities after they have had appropriate training at Cornell, or at Cornell and London. They are tenable for up to twenty-two months for the purpose of dissertation research. Recipients of London-Cornell Field Research Grants may conduct research in any part of Southeast Asia. Stipends range up to $12,000 for twenty-two months including travel and research expenses.

Cornell-Philippines Field Research Fellowships are available, under a grant from the Rockefeller Foundation, for advanced graduate

students who plan to write dissertations in the social sciences or the humanities, based upon field research in the Philippines. Fellowship support is for ten to fifteen months in the Philippines and includes living costs, local transport, and roundtrip transportation from the United States for the graduate student and dependent wife or husband.

National Defense Foreign Language Fellowships, Title VI, are offered by the United States Office of Education for study during the academic year, the summer, or both. Application should be made to Sage Graduate Center, Cornell University. Information about Foreign Area Training fellowships, administered by the Social Science Research Council, may be obtained by writing to the Foreign Area Fellowships Program, 444 Madison Avenue, New York, New York 10022. Graduate students may also apply for other fellowships, teaching fellowships, assistantships, and scholarships offered by the University and its departments.

Additional information on the Program and the various fellowships and awards may be obtained by writing to the Director, Southeast Asia Program, 108 Franklin Hall.

Soviet Studies

COMMITTEE ON SOVIET STUDIES: George Gibian, Chairman; Urie Bronfenbrenner, M. Gardner Clark, Jack Fisher, Walter Galenson, Richard Leed, Walter Pintner, Myron Rush, George Staller.

OTHER FACULTY MEMBERS IN SOVIET STUDIES: Patricia Carden, Frederick Foos, Antonia Glasse, Martin Horwitz, Augusta Jaryc, Hugh Olmsted, Nicholas Troizkij, Marla Wykoff.

The University offers a number of courses and seminars on the Soviet Union as well as pre-1917 Russia. Instead of a separate area program, graduate students have a choice of majors and minors in the established Fields of the Graduate School. Some of the subjects focus on area specialization: Russian history, Russian literature, Slavic linguistics. Other subjects combine area specialization with a nonarea framework: comparative government, economic planning, regional planning, social psychology.

Graduate students pursuing Soviet Studies in any of these subjects are expected to attain proficiency in the Russian language either before entering the Graduate School or soon thereafter.

The University's academic activities related to Russia are coordinated by the Committee on Soviet Studies. The Committee also sponsors a colloquium for faculty members and graduate students in Soviet Studies. In the Soviet Studies Graduate Study in the John M. Olin Library, major reference works and key current periodicals from and about the U.S.S.R. are brought together.

The Committee on Soviet Studies selects a limited number of graduate students each year as research assistants. The Russian section of the Division of Modern Languages and the Department of Russian Literature also appoint several graduate students annually as teaching

fellows in the Russian language. For other teaching fellowships, fellowships and scholarships, students apply directly to the Graduate School or to the department concerned. N.D.E.A. Title IV and Title VI fellowships are available in various subjects.

FACULTY SPECIALIZATIONS

ECONOMICS: M. Gardner Clark, Walter Galenson, George J. Staller.

HISTORY: Walter M. Pintner.

LANGUAGES AND LINGUISTICS: Frederick Foos, Richard Leed, Mrs. Augusta Jaryc, Hugh Olmstead, Marla Wykoff.

LITERATURE: Miss Patricia Carden, George Gibian, Miss Antonia Glasse, Martin Horwitz, Hugh Olmstead.

POLITICAL SCIENCE: Myron Rush.

PSYCHOLOGY: Urie Bronfenbrenner.

REGIONAL AND CITY PLANNING: Jack C. Fisher.

Inquiries about fellowships and other aspects of Soviet Studies should be addressed to Professor George Gibian, Chairman, Committee on Soviet Studies, Goldwin Smith Hall.

OTHER PROGRAMS AND CENTERS

American Studies

COMMITTEE ON AMERICAN STUDIES: David B. Davis, Chairman; Stuart M. Brown, Jr., Douglas E. Dowd, Robert H. Elias, Andrew Hacker, Clinton Rossiter, S. Cushing Strout, Robin M. Williams, Jr.

Although there is no formal program leading to a degree in American Studies, candidates for the doctorate in English and History will find ample opportunity to do interdisciplinary work in conjunction with a major in the American area of their Field. There are members of the staff in both Fields who are professionally trained and currently active in the study of the interrelationships of American intellectual, literary, and social history, so that a student concentrating in American literature or American history may take advantage of the freedom permitted by Graduate School regulations and, in collaboration with his special committee, readily build an individual doctoral program that systematically embraces more than a single discipline. Inquiries concerning opportunities in this area should be addressed to Professor David B. Davis, Chairman, American Studies Committee, West Sibley Hall.

Brookhaven National Laboratory

Cornell is one of nine eastern universities participating in Associated Universities, Inc. (AUI). Operating under contract with the Atomic Energy Commission, this corporation has the responsibility for the

management of Brookhaven National Laboratory. The laboratory provides unusual research facilities for studies in biology, chemistry, applied mathematics, medicine, physics, high-energy particle physics, and reactor and nuclear engineering.

Graduate students may participate in research at Brookhaven by association with Cornell staff members who are engaged in research at the laboratory. Members of a variety of science departments at Cornell are currently involved in programs at Brookhaven. The laboratory also offers temporary summer appointments to a limited number of selected graduate and undergraduate students in science or engineering.

Center for Advancement of Education

The Center for Advancement of Education represents the commitment of the total University to educational research and development. Members of the Center are drawn from various academic units. Projects are carried out under the auspices of the Center; such projects may increase to reflect the interests of faculty members. At present, research programs in language development and literacy, in mathematics, and in science education are under way. In addition, a research program on the administration of higher education as well as on the undergraduate collegiate curriculum are being planned.

The Center provides predoctoral and postdoctoral training through research assistantships, training grants, and postdoctoral fellowships. For information write to the Director, Center for Advancement of Education, 320 Wait Avenue.

Center for Aerial Photographic Studies

Photographic interpretation has applications in agriculture, engineering, geology, and city and regional planning. The Center for Aerial Photographic Studies offers a broad program in various scientific fields for training personnel in aerial photographic interpretation. The objectives are, first, to train scientists who will be able to use aerial photographs for surveys and planning in fields where they are needed and second, through research to extend the use of aerial photographs into all fields which can be benefitted.

The Center comprises a staff of educators, scientists, and technicians experienced in research and the application of aerial photographs to their respective fields. The program consists of primary courses in interpretation of aerial photographs, map reproduction, photogrammetry, cartography and map projections, together with specialized study in a particular field of the candidate's choice, such as agricultural development, national resource explorations, city planning, or engineering project planning.

For more information, write to Professor Donald J. Belcher, Director, Center for Aerial Photographic Studies, Hollister Hall.

Center for Housing and Environmental Studies

The purposes of the Center for Housing and Environmental Studies are to aid and guide basic research in the field of man's shelter and environment, to facilitate graduate study, and to aid the flow of information among colleges and departments and between the University and sources of information off campus. A small central staff assists in the initiation and conduct of projects.

The facilities of the Center for Housing and Environmental Studies are available to faculty members and graduate students in all Fields. Through the Center, students who cut across traditional lines of research may draw upon the knowledge and experience of specialists in such various subject areas as design, materials, equipment, structural methods, environment, family living, economics and finance, government, and health. The Director of the Center is Professor Glenn H. Beyer, West Sibley Hall.

There are two divisions in the Center, one focusing on urban and the other on regional problems. The Division of Urban Studies is under the direction of Professor Barclay G. Jones, Associate Director of the Center, West Sibley Hall; and the Division of Regional Studies is under the direction of Professor Jack C. Fisher, Assistant Director of the Center, West Sibley Hall.

Center for Radiophysics and Space Research

The Center for Radiophysics and Space Research unites research and graduate education carried on by several academic departments in the space sciences. It furnishes administrative support and provides facilities for faculty members and graduate assistants who are engaged in space research activities, and it offers opportunity for graduate students to undertake thesis work leading to the degrees of Master of Science and Doctor of Philosophy. A student's major professor can be chosen from the following Fields in the Graduate School: Aerospace Engineering, Applied Physics, Astronomy and Space Sciences, Electrical Engineering, Physics.

Thesis research in the following areas is now possible:

(a) Astronomy and Astrophysics. Astronomical aspects of cosmic rays, gamma-radiation, x rays, neutrinos; cosmology; experimental studies and theory relating to the surface of the moon and the planets; processes in the interstellar gas; solar-system magnetohydrodynamics; stellar statistics; theory of stellar structure, stellar evolution, nuclear processes in stars.

(b) Atmospheric and Ionospheric Radio Investigations. Dynamics of the atmosphere; incoherent electron scattering; study of refraction, scattering, attenuation due to the inhomogeneous nature of the troposphere and ionosphere; theory and observation of propagation of radio waves in ionized media such as the ionosphere.

(c) Radar and Radio Astronomy. Distribution and classification of radio sources; radar investigations of the moon and planets; solar radio observations; studies of gaseous nebulae.

(d) Space Vehicle Instrumentation. Instrumentation relating to lunar exploration; magnetic field measurements; tenuous gas and particle flux measurements; infrared observations from rockets.

The facilities of the Center include the lunar surface and electronics laboratory on the Cornell campus, the radio astronomy and ionospheric laboratories close to Ithaca, and the Arecibo Ionospheric Observatory in Puerto Rico. At Arecibo an extremely sensitive radio telescope and an unusually powerful space radar are available for use by qualified graduate students. In addition, certain facilities of Sydney University, Australia, are available through the Cornell-Sydney University Astronomy Center (see below).

Cornell-Sydney University Astronomy Center

The Center is an inter-University organization designed to create a larger pool of facilities and skills for research in astronomy and related fields than would be separately available to either university. Graduate students can be interchanged between the two institutions whenever appropriate for the research work in which they are engaged. Both universities recognize research supervision extended by the sister university, and the time spent by a student on thesis work in the sister university can be accepted toward residence requirements with the proviso that the approval of the home research supervisor is given and also that the home university bylaws are not contravened.

The facilities available through the Center, in addition to those of Cornell's Center for Radiophysics and Space Research, are the one-mile by one-mile Mills Cross situated at Hoskinstown, New South Wales; the stellar intensity interferometer situated at Narrabri, New South Wales; the Criss-Cross, the Shain Cross, and Mills Cross situated at Fleurs, New South Wales; the Wills Plasma Physics Department, the Basser Computing Department, the Falkner Nuclear Department, and the facilities of the cosmic ray group at the University of Sydney. The Center includes H. Messel, R. Hanbury Brown, W. N. Christiansen, C. B. A. McCusker, and B. Y. Mills from the University of Sydney faculty.

Further information can be obtained from Professor T. Gold, Joint Director, Cornell-Sydney University Astronomy Center, Space Science Building.

Division of Biological Sciences

The Division of Biological Sciences was established in 1964 to bring together into a single administrative unit a number of investigators and teachers representing a broad spectrum of interests in basic biology. Its members hold appointments in one or more of four schools and colleges but serve the University as a whole through the Division. The

Division is responsible for all the undergraduate teaching of biology, including the establishment of requirements for the major in its various branches. It also has the primary responsibility for the promotion of research in basic biology, and its members engage in graduate teaching through participation in appropriate Fields in the Graduate School Faculty. At present the following subject areas are represented by separate sections of the Division: biochemistry and molecular biology; ecology and systematics; genetics, development, and physiology; microbiology; and neurobiology and behavior. A number of graduate fellowships, teaching fellowships, research assistantships, and traineeships are available through the Division. For further information, contact Dr. Robert Morison, 201 Roberts Hall.

Materials Science Center

The Materials Science Center (MSC) at Cornell is an interdisciplinary laboratory created to promote research and graduate student training in all phases of the science of materials. The subjects of study represented in the MSC program are applied physics, chemistry, electrical engineering, materials engineering, materials science, metallurgy, and physics.

The extent of the benefits a graduate student may derive from the MSC program depends on the actual research he pursues. If the student chooses to follow the more conventional course of becoming a specialist in one specific area, the MSC program could help him by providing new equipment, financial assistance through research assistantships, or, in some cases, the help of a technician to carry out routine measurements.

If the student wishes to follow a program of considerably more breadth than usual in his research training, the MSC program provides an additional advantage. Several central facilities have been set up where more specialized apparatus such as crystal-growing furnaces, high-pressure equipment, x ray and metallography equipment, electron microscopes, etc., are available to all MSC members and their students. In addition to the equipment, expert advice on its use and the interpretation of the results will be available. In these central facilities, it is expected that the student will come in contact with students from other disciplines, resulting in a mutually profitable interaction.

The office of the Director of the Materials Science Center, Professor Henri Sack, is in Room 627, Clark Hall.

Military Science, Naval Science, and Aerospace Studies

(ROTC, NROTC, and AFROTC)

The advanced course in military science (Army ROTC), naval science (Naval ROTC), and aerospace studies (Air Force ROTC) is open to

graduate students who have satisfactorily completed a basic course in ROTC or who enroll in a two-year ROTC program. Successful completion of the two-year advanced ROTC course will qualify a graduate student for appointment as a Second Lieutenant in the U.S. Army, Air Force, or Marine Corps Reserve; or Ensign, U. S. Naval Reserve; or as Second Lieutenant in the Regular Army or Air Force. Interested graduate students should consult the *Announcement of Officer Education* and apply to the Professor of Military Science, the Professor of Naval Science, or the Professor of Aerospace Studies (ROTC), Barton Hall.

Statistics Center

The methods of statistics find important applications in many diverse fields of research. It is therefore necessary that (1) subject matter specialists be able to obtain assistance in using or developing statistical theory, (2) students who intend to do research work in a particular field which makes extensive use of statistical methods receive adequate training in statistics, and (3) individuals be trained as statisticians.

The staff members of the various schools and colleges of Cornell University who are interested in the development and application of statistical methods are associated with the Cornell Statistics Center. A major responsibility of the Center is to provide a focal point to which individuals, projects, and departments may come to receive assistance and guidance with respect to the statistical aspects of research and training programs.

The Acting Director of the Center is Professor Philip J. McCarthy, Ives Hall.

Water Resources Center

The Center is an interdisciplinary organization serving the entire University at the graduate study and research level. It purpose is to promote and coordinate a comprehensive program in water resources planning, development, and management in such areas as the sciences, engineering, agriculture, law, economics, government, regional planning, and public health.

Its responsibilities are to undertake water resources research in engineering, in the physical, biological, and social sciences, and in the humanities; to encourage and contribute to graduate studies in water resources; to coordinate research and training activities in areas concerned with water resources; to encourage new combinations of disciplines in research and training which can be brought to bear on water resources problems; to disseminate the results of research; and to develop and operate central facilities which may be needed to serve participants in research and training.

Correspondence concerning the Center should be directed to Professor L. B. Dworsky, Director, Water Resources Center, Hollister Hall.

Correspondence related to graduate study in the Field of Water Resources should be directed to the Field Representative, Professor C. D. Gates, Hollister Hall.

SPECIAL FACILITIES AND SERVICE ORGANIZATIONS

Cornell Aeronautical Laboratory

The Laboratory, a separate corporation wholly owned by Cornell University, is in Buffalo, New York. Applied and fundamental research in the aeronautical sciences and allied areas is conducted in this completely equipped laboratory under contracts mainly with government and industry. Close relationships, both research and educational, are maintained with the campus in Ithaca.

New York State Agricultural Experiment Station at Geneva

The New York State Agricultural Experiment Station was established in 1880 to promote agriculture through scientific investigations and experimentation. It is located at Geneva, fifty miles from Ithaca, and has been under the administration of Cornell University since 1923.

Professors on the Geneva staff are eligible to serve as members of the Special Committees of graduate students along with professors on the Ithaca campus of the University. Normally the graduate training provided at Geneva consists of research experience and supervision of the student's work on a thesis problem. The formal course work part of the student's training program is given on the Ithaca campus. Students who plan to do part of their graduate work at Geneva should correspond with their major advisers or with the Dean of the Graduate School concerning regulations as to residence, Special Committees, etc.

The Station is equipped to care for graduate students in certain specific lines of research, viz., bacteriology, chemistry, economic entomology, food technology, plant pathology, pomology, seed investigations, and vegetable crops. Ample facilities are available for graduate research under laboratory, greenhouse, pilot plant, insectary, orchard, and other field conditions.

Certain phases of the investigations now being conducted at the Station and other problems for which the facilities of the Station are suitable may be used as thesis problems by graduate students.

The Director is Professor D. W. Barton, who may be addressed at the New York State Agricultural Experiment Station, Geneva.

Office of Computer Services

The principal computing facility at Cornell is an IBM 360 Model 65 located at Langmuir Laboratory at the Cornell Research Park. The system is equipped for remote access of several kinds, and the operating system is designed so that very few users find it necessary to visit Langmuir. The primary terminals are high-speed reader-printers located in Upson, Clark, and Warren Halls. While these are remote job-entry and delivery devices rather than conversational terminals, they permit convenient access, job turnaround-time in terms of minutes, and the use of on-line files. Each of these terminals is the core of a small computing center, with auxiliary equipment, consulting assistance, reference material, and work space. In addition to these high-speed terminals, teletypewriter terminals are available to individual projects that require interactive capability.

Two IBM 1800 computers that control various real-time laboratory devices are also linked directly to the 360/65. These machines provide graphical input-output capability and an analog-digital interface.

This computing system is busy but not saturated, and use by graduate students is encouraged.

The Office of Computer Services is responsible for the operation of this system and for the provision of consulting and programming assistance. The Office cooperates with the Department of Computer Science in providing courses in programming and computing techniques. Both organizations employ a number of graduate students on assistantships and part-time appointments for this work.

For further information write to the Office of Computer Services, Langmuir Laboratory.

Photo Science Studios

The University owns and operates the Photo Science Studios, which create or cooperate in the creation of photographic studies and visual aids of all kinds.

The extension services of the New York State Colleges, which form integral parts of the University, disseminate knowledge through an intensive program of publication, photography, and recording supervised by professional staffs. Materials produced by graduate students may find outlets through these channels.

University Press

Cornell University Press, founded by Andrew D. White in 1869, was the first university press in America and is among the leaders in number of volumes published annually. The Press publishes scholarly books on nearly every academic subject, serious nonfiction of general interest, and advanced or experimental textbooks for use in universities. The imprint of Comstock Publishing Associates, a division of the Press, is

placed on certain books in the biological sciences. The Press also publishes a distinguished paperbound series, Cornell Paperbacks.

Other Research Units

Some other research units allied with the University, either as wholly owned and operated divisions or as wholly or partially autonomous organizations with which the University has a working agreement, are the Sloan-Kettering Cancer Research Institute in New York City, through the Graduate School of Medical Sciences, and the Veterinary Virus Research Institute in Ithaca.

Cornell is also one of fourteen founding members of the University Corporation for Atmospheric Research which, under National Science Foundation support, operates the National Center for Atmospheric Research at Boulder, Colorado.

In addition, opportunities for formal study, field work, and independent research by Cornell graduate students are available in many institutions, laboratories, and libraries both in the United States and in other countries. For example, the Cornell-Harvard Archaelogical Exploration at Sardis, Turkey, and the Museum of Northern Arizona at Flagstaff, Arizona, both provide opportunities for field research related to doctoral work of Cornell graduate students. Information on that kind of arrangement is available directly from the Field Representatives.

GRADUATE SCHOOL OF MEDICAL SCIENCES

The opportunity for graduate work leading to advanced general degrees was first offered in the Medical College in 1912 in cooperation with the Graduate School of Cornell University. In June 1950, the trustees of Cornell University entered into an agreement with the Sloan-Kettering Institute for Cancer Research whereby a new division of the Medical College, namely, the Sloan-Kettering Division, was created for the purpose of offering additional opportunities for graduate study toward advanced degrees, thus extending the areas of the basic sciences.

That expansion of the New York City component of the Graduate School resulted in the establishment in January, 1952, of the Graduate School of Medical Sciences which, with the approval of the faculty of the Graduate School of Cornell University, was given the full responsibility for administrative matters related to the advanced general degrees granted for study in residence at the New York City campus of Cornell University.

DEGREES. The general degrees of Ph.D. and M.S. are awarded for advanced study and scholarly, independent research in the fields of anatomy, biochemistry, biomathematics, biophysics, biostatistics, cell biology, genetics, microbiology, neurobiology and behavior, pharmacology, and physiology.

FACILITIES. The facilities for graduate work at the Graduate School of Medical Sciences include those of the Medical College and of the Sloan-Kettering Division. The five buildings of the Medical College, extending along York Avenue from 68th to 70th Street in New York City, contain the lecture rooms, student laboratories, library, and research facilities for graduate and undergraduate work. The Sloan-Kettering Division is located in the Sloan-Kettering Institute and the Kettering Laboratory on East 68th Street in New York City, and in the Walker Laboratory in Rye, New York. The special facilities and experienced investigators of the Sloan-Kettering Division offer ample opportunity for advanced graduate work in the basic science aspects of research related to cancer and allied diseases.

FINANCIAL ASSISTANCE. Predoctoral fellowships are available to qualified applicants. The fellowships may be renewed yearly providing the academic performance of the fellowship holders is satisfactory. Teaching fellowships and research assistantships are available to qualified graduate students in some departments of the Medical College. In addition to a stipend, the costs of tuition and fees are defrayed for those students receiving financial assistance.

FURTHER INFORMATION. Information on financial assistance and the entire program of the Graduate School of Medical Sciences is provided in the *Announcement of the Graduate School of Medical Sciences.* Requests for that Announcement should be addressed to the Graduate School of Medical Sciences, Cornell University Medical College, 1300 York Avenue, New York 10021.

FIELDS OF INSTRUCTION

REPRESENTATIVES. Since instruction in the Graduate School is primarily individual, those interested in becoming students are encouraged to communicate with individual members of the faculty with whom they may want to study. Personal interviews in advance of formal application for admission are especially encouraged. For the benefit of those who are not acquainted with appropriate members in the Field or Fields of their interest, each Field has selected a representative, as director of graduate studies, to whom inquiries may be addressed.

AEROSPACE ENGINEERING

Faculty: Peter L. Auer, P. C. Tobias de Boer, Albert R. George, Geoffrey S. S. Ludford, Edwin L. Resler, Jr., William R. Sears, A. Richard Seebass, Shan-fu Shen, Donald L. Turcotte.

Field Representative: A. Richard Seebass, 294 Grumman Hall.

MAJOR SUBJECT	MINOR SUBJECTS
Aerospace Engineering	Aerospace Engineering Aerodynamics

The requirement for admission in this Field is a Bachelor's degree in engineering or the physical sciences. It is not recommended that candidates apply for admission at midyear, except in unusual cases.

The language requirement for the Ph.D. is one language in addition to the candidate's native language: either French, Russian, or German at the level of the ETS Language Examination, or English.

In this Field of graduate study emphasis is placed on the aerospace sciences rather than proficiency in present-day techniques. Consequently, graduate students having aerospace engineering as their major subject will be urged to select as their minor subjects the basic sciences, such as chemistry, mathematics, mechanics, and physics. There are several special fellowship awards supported by the Cornell Aeronautical Laboratory available to students in this Field.

Much of the research carried out in this Field at Cornell is concerned with fundamental problems in the dynamics of fluids, including plasmas and chemical reactions at high temperature. Whenever possible, these investigations combine the techniques of theory and laboratory experiment, making use of the experimental facilities of the Graduate School of Aerospace Engineering on the campus. In every investigation, an attempt is made to correlate theory with observation and practical experience.

A group working under the direction of Professors de Boer and Resler is investigating the dynamics of gases at extreme temperatures. Generally speaking, their interests lie in matters in which the sciences of physics and chemistry are finding application to the aerodynamics of propulsion systems and to flight of missiles and space vehicles.

The branch of fluid mechanics called magnetohydrodynamics now forms an essential part of the activities of the Graduate School of Aerospace Engineering; Professors Resler, Sears, and Turcotte are engaged in this research, both in theory and in the laboratory. Professor Ludford of the Department of Theoretical and Applied Mechanics is exploring the mathematical theory

of this phase of fluid mechanics. Professor Auer is concerned with those aspects of plasma physics concerned with the higher temperature collisionless regime appropriate to possible fusion applications. This interest brings the School into close contact with several other departments of the University (including the Center for Applied Mathematics and the Center for Radiophysics and Space Research). Professors George, Seebass, and Shen and their students are pursuing investigations in the area of rarefied-gas dynamics, hypersonics, basic fluid mechanics, and advanced aerodynamics, which are related to the other aspects of real-gas dynamics and air chemistry mentioned above. The staff is also pursuing studies of the sonic boom and associated problems concerned with high performance aircraft. Close contact is maintained with the work in Thermal Engineering, which is housed in Upson Hall adjacent to this School. The School also maintains active interest and research in subjects basic to modern space vehicle and propulsion-system design, including problems of missile dynamics, trajectories, and orbits. Research in chemical kinetics is conducted with the cooperation of Professor S. H. Bauer of the Department of Chemistry, and research in structures and materials is carried out in cooperation with the Field of Theoretical and Applied Mechanics and the Materials Sciences Center. This brief description is, of course, not all-inclusive and other topics of research are under study. Further details may be obtained by writing to the Director of the Graduate School of Aerospace Engineering, Grumman Hall.

Candidates for an advanced degree with a major in this Field who do not already hold the Master's degree are encouraged to matriculate first as candidates for the professional degree, Master of Engineering (Aerospace), under the jurisdiction of the Graduate School of Aerospace Engineering. Information concerning this School and the degree of Master of Engineering (Aerospace) will be found in the *Announcement of the College of Engineering*.

Courses

7101. ADVANCED KINETIC THEORY

Credit three hours. Fall. Mr. de Boer.

The Boltzmann equation. Solution for gas in equilibrium. Collision frequency and mean free path calculations. Conservation equations. Review of Enskog-Chapman theory of transport coefficients. Grad's thirteen moment equations. The BGK equation. The BBGKY theory.

7102. GASDYNAMICS

Credit three hours. Spring. Mr. Resler.

Strong shock waves and their use in the production and study of high temperature gases. High temperature chemical kinetics and its application to hypersonic external flows, rocket internal flows, and other phenomena of current interest. Chemical relaxation effects on flow fields and the method of characteristics including chemical reactions. Experimental techniques.

7103. DYNAMICS OF RAREFIED GASES

Credit three hours. Spring. Prerequisites: 7101 and 7102. Mr. Shen.

Flow regimes according to the Knudsen number. Theories of the shock structure at high Mach numbers. Boundary conditions at a solid wall. Slip-flow conditions. Free-molecule flows. Eigen function expansion of the linearized Boltzmann equation. Full-range and half-range moment methods. The model equation approach and recent developments for handling the transition regime.

7104. ADVANCED TOPICS IN HIGH TEMPERATURE GASDYNAMICS

Credit three hours. Either term. Prerequisites: 7101 and 7102.

Current topics relating to present engineering practice and/or research interests of the faculty and staff.

7201. INTRODUCTORY PLASMADYNAMICS

Credit three hours. Fall. Mr. Auer.

Macroscopic and microscopic properties of plasmas. Wave motion and stability. Character of laboratory-produced and naturally occurring plasma systems. Application to power conversion and space propulsion. Introduction to controlled thermonuclear research. Reference text: *Plasma Physics in Theory and Application,* Ed. W. B. Kunkel.

7202. INTRODUCTORY MAGNETOHYDRODYNAMICS

Credit three hours. Spring. Mr. Turcotte.

Basic equations of magnetohydrodynamics. Flow problems. Hydromagnetic shock waves. The pinch effect and instabilities. Tensor conductivity and excess electron temperature.

7203. INTERMEDIATE PLASMA PHYSICS

Credit three hours. Spring. Prerequisite: 4561 or 7201 or equivalent. Mr. Auer.

Collective oscillations in a cold plasma; waves in a warm plasma; application to natural phenomena. Nonlinear theory of collision-free shocks. Quantum effects in solid state plasma waves; plasma-phonon interactions. Introduction to radiation and scattering in plasmas. At the level of Stix, *Theory of Plasma Waves,* and Bekefi, *Radiation Processes in Plasmas.*

7301. FLUID MECHANICS

Credit three hours. Fall. Mr. George.

The continuum and the stress tensor. Vectors and tensors. Hydrostatics. Strain and rate-of-strain tensors. Constitutive equations. The ideal elastic continuum. Equilibrium and compatibility equations, boundary conditions. Plane stress and strain. The stress function. Elastic energy. St. Venant's principle. The Newtonian fluid, viscosity and bulk viscosity Navier-Stokes equations. Poiseuille flow, Rayleigh and Stokes problems. The concept of the boundary layer. The ideal-fluid approximation. Kelvin and Helmholtz theorems. Irrotational flows.

7302. AERODYNAMICS

Credit three hours. Spring. Mr. Sears.

Laplace's equation. Source, sink, and doublet. Vortices. Biot-Savart theorem, the flow field of a vortex. Spherical and cylindrical harmonics. Methods of singularity distributions. Complex-variable methods. Wing theory. Acoustics. Compressible flows, subsonic and supersonic. Shock waves. Hypersonic flow. Rotational flows. Magnetohydrodynamics. Flow in the boundary layer, Prandtl theory. Heat transfer, separation.

7303. COMPRESSIBLE FLUID FLOW

Credit three hours. Fall. Mr. Seebass.

Aerodynamics of compressible fluids. Brief review of linear theories. Improvements on linear theory. Sonic boom. Role of entropy in supersonic flows. Shock wave interactions. Exact theories: method of characteristics for rotational reacting flows; hodograph transformation; conical flows. Transonic flow theory and similitude. Viscous effects in compressible flows. Other topics of current interest.

7304. THEORIES OF VISCOUS FLOWS

Credit three hours. Fall. Prerequisites: 7301 and 7302. Mr. Shen.

Exact solutions of the Navier-Stokes equations. The small Reynolds number approximation. The boundary layer theory and the techniques for its solution. Compressibility effects. Stability of laminar flows. Turbulence.

7305. HYPERSONIC FLOW THEORY

Credit three hours. Spring. Prerequisites: 7301 and 7302. Mr. George or Mr. Seebass.

Hypersonic small disturbance theory and the related similitude; blast wave analogy; entropy layers. Newtonian theory and shock layer structure. Constant density solutions. The blunt body problem; numerical techniques. Viscous and real gas effects: ideal dissociating gas; viscous interactions; other real gas phenomena.

7801. RESEARCH IN AEROSPACE ENGINEERING

Credit to be arranged. Prerequisite: admission to the Graduate School of Aerospace Engineering and approval of the Director.

Independent research in a field of aerospace science. Such research must be under the guidance of a member of the staff and must be of a scientific character.

7901. AEROSPACE ENGINEERING COLLOQUIUM

Credit one hour.

Lectures by Cornell staff members, graduate students, and visiting scientists on topics of interest in aerospace science, especially in connection with new research.

7902. SEMINAR IN AEROSPACE ENGINEERING

Credit two hours. Prerequisite: approval of the Director.

Study and discussion of topics of current research interest in aerospace engineering. Members of the seminar will prepare and deliver reports on these topics, based on published literature.

7903. PLASMA PHYSICS COLLOQUIUM

Credit one hour. Fall and spring.

Lectures by staff members, graduate students, and outside scientists on topics of current interest in plasma research.

AGRICULTURAL ENGINEERING

Faculty: Richard D. Black, J. Robert Cooke, Edward W. Foss, Orval C. French, Ronald B. Furry, Richard W. Guest, Wesley W. Gunkel, Fred G. Lechner, Gilbert Levine, Robert T. Lorenzen, David C. Ludington, Everett D. Markwardt, William F. Millier, Gerald E. Rehkugler, Norman R. Scott, E. Stanley Shepardson, John C. Siemens, James W. Spencer, Clesson N. Turner.

Field Representative: Wesley W. Gunkel, 226 Riley-Robb Hall.

MAJOR AND MINOR SUBJECTS

Agricultural Engineering
Agricultural Structures
Electric Power and Processing
Power and Machinery
Soil and Water Engineering

Ph.D. candidates are required to have one major subject selected from the above list and two minor subjects. One minor subject may be selected from the above list, and at least one minor subject must be selected in a Field outside Agricultural Engineering. M.S. candidates are required to take Agricultural Engineering as their major subject and to select one minor outside the Field. Candidates for either the doctorate or the Master's degree with the major outside the Field may select any subject as a minor.

ADMISSION REQUIREMENTS. To be considered for admission an applicant must have a baccalaureate degree in an area of engineering, physical science, or biological science from a faculty or university of recognized standing. Training in the engineering and biological sciences is necessary. Any deficiencies in these areas in the undergraduate training will need to be satisfied early in the advanced degree program. The applicant must present evidence of promise in advanced study and research as indicated by past scholastic achievement and recommendations from his undergraduate or graduate institution.

Although it is not required by the Field, applicants applying for fellowships and scholarships are urged to take from the Educational Testing Service both the Graduate Record Examination Aptitude and Advanced Engineering Tests. Scores should be sent to the Cornell Graduate School as part of the application.

LANGUAGE REQUIREMENTS FOR ADVANCED DEGREES. There is no general language requirement for either the M.S. or the Ph.D. in the Field. However, a candidate's Special Committee may require language to be included in the student's program.

EXAMINATIONS. The final examination for the M.S. may be oral, or oral and written. Students continuing for the Ph.D. in the Field may, with the permission of their Special Committee for the Ph.D. program, combine the M.S. final examination with the Admission to Candidacy Examination, which, together with the Final Examination on the thesis, is required of all Ph.D. candidates.

RESEARCH AND STUDY OPPORTUNITIES. A broad spectrum of research and study activity is available in Agricultural Engineering. A thesis based on research effort is required for both the M.S. and Ph.D. degrees. A partial list of the general areas of research interest and the faculty members associated with these interests are listed below. Specific topics of mutual interest may also be selected. If you desire information about current research projects, the Field Representative will direct your inquiry to the faculty member best able to answer your request.

Agricultural Engineering: All faculty members. Agricultural mechanization, agricultural waste management, bioengineering, engineering properties of biological materials, low-cost roads, materials handling, safety engineering.

Agricultural Structures: Ronald B. Furry, Robert T. Lorenzen, Norman R. Scott. Structural analysis and design, production systems synthesis, structural-biological relationships, environmental composition and control, biological response to environment, thermodynamic processes.

Electric Power and Processing: Ronald B. Furry, Richard W. Guest, David C. Ludington, E. Stanley Shepardson, Clesson N. Turner. Electrical control systems, processing of agricultural materials, application of electromagnetic radiation to agriculture.

Power and Machinery: J. Robert Cooke, Richard W. Guest, Wesley W. Gunkel, Everett D. Markwardt, William F. Millier, Gerald E. Rehkugler, E. Stanley Shepardson, John C. Siemens. Agricultural machinery design and development, terramechanics, crop harvesting, handling and processing systems, metering and distribution of agricultural chemicals, physical and biological factors pertaining to machine design such as soil mechanics in relation to seedling development.

Soil and Water Engineering: R. D. Black and G. Levine. Surface water hydrology, flow in porous media, irrigation efficiency, soil-plant-water relationships, waste water disposal, hydraulics.

Professional Degree

The Department of Agricultural Engineering also offers the professional degree of Master of Engineering (Agricultural) which is intended primarily for those students who plan to enter engineering practice, and not for those who expect to study for the doctorate. This program consists of courses which are intended to develop the student's background in engineering design as well as strengthen his fundamental engineering base. Of the required thirty hours, six consist of engineering design experience involving individual effort and a formal report.

Admission to the Master of Engineering (Agricultural) program is open to persons who have been granted Bachelor's degrees, or the equivalent, and who have sufficient training to indicate that they can profitably study the advanced courses offered for these students in engineering. A student can choose to concentrate his studies in one of the sub-areas of Agricultural Engineering or take a broad program without specialization.

Graduate Courses

501. SIMILITUDE ENGINEERING

Spring term. Credit three hours. Two lectures, one laboratory. Time and place to be arranged. Associate Professor Furry.

Similitude methodology, including the use of dimensional analysis to develop general equations to define physical phenomena; model theory; distorted models; and analogies, including the use of electronic analog computers. Introduction to a variety of applications in engineering. It is preferred that students know how to program in FORTRAN, although knowledge of CUPL is acceptable.

502. INSTRUMENTATION

Fall term. Credit three hours. Two lectures, one laboratory. Time and place to be arranged. Assistant Professor Scott and staff.

Application of instrumentation to physical and biological measurements in agricultural engineering research, including measurement of force, displacement, velocity, acceleration, temperature, humidity, fluid flow, and electrical impedance and potential.

504. BIOLOGICAL ENGINEERING ANALYSIS

Fall term. Credit three hours. Three lectures. Riley-Robb 225. Time to be arranged. Prerequisite: consent of the instructor or Engineering 1151. Assistant Professor Cooke.

Engineering problem-solving techniques will be examined. Particular attention will be given to the formulation of biological problems in an engineering context. Experience will be gained in problem definition, mathematical formulation, and interpretation of results. Principles of feedback control theory will be studied and applied to biological and technological systems.

551–552. AGRICULTURAL ENGINEERING PROJECT

Fall and spring term (both terms required for M.E. (Agr.) degree). Credit three hours per term. Time and place to be arranged. Staff.

Comprehensive design projects utilizing real engineering problems to present fundamentals of agricultural engineering design. Emphasis on formulation of alternate design proposals, including economics and nontechnical factors, and complete design of the best alternative.

600. SPECIAL TOPICS

Fall or spring term. Credit one or more hours. Time and place to be arranged. Staff.

Special work in any area of agricultural engineering on problems of special interest to the students and faculty.

601. GENERAL SEMINAR

Fall and spring terms. Fall term required of all graduate students majoring in the Field. Spring term optional. M 12:30. Riley-Robb 400. Staff.

Presentation and discussion of research and special developments in agricultural engineering.

602. POWER AND MACHINERY SEMINAR

603. SOILS AND WATER ENGINEERING SEMINAR

604. AGRICULTURAL STRUCTURES SEMINAR

Seminars 602, 603, 604. Spring term. Credit one hour. Time and place to be arranged. Staff.

Thorough investigation and discussion of research or new developments in an area of special interest to those enrolled.

Undergraduate Courses Open to Graduate Students

[461. AGRICULTURAL MACHINERY DESIGN]

Spring term. Credit three hours. Prerequisite: Engineering 3331 or the equivalent. Two lectures, one laboratory. Time and place to be arranged. Professor Gunkel. Offered in alternate years. Not offered in 1967–68.

The principles of design and development of agricultural machines to meet functional requirements. Emphasis is given to computer-aided analysis and design, stress analysis, selection of construction materials, and testing procedures involved in agricultural machine development.

462. AGRICULTURAL POWER

Fall term. Credit three hours. Prerequisite: Engineering 212 or the equivalent. Two lectures, one laboratory. Time and place to be arranged. Assistant Professor Siemens. Offered in alternate years.

Basic theory, analysis, and testing of internal combustion engines specifically

for use in farm tractors and other agricultural power applications. Tractor transmissions. Nebraska Tractor Tests, soil mechanics related to traction, stability, shop dynamometers, fuels, hydraulic equipment.

[463. PROCESSING AND HANDLING SYSTEMS FOR AGRICULTURAL MATERIALS]

Spring term. Credit four hours. Three lectures, one laboratory. Time and place to be arranged. Associate Professor Ludington. Offered in alternate years. Not offered in 1967–68.

Processes such as size reduction, separation, metering, drying, and refrigeration will be studied. Psychrometrics, fluid flow measurement, and an introduction to system engineering and electrical controls for agricultural applications is included. The student should know how to program in FORTRAN or CUPL.

471. SOIL AND WATER ENGINEERING

Spring term. Credit three hours. Prerequisites: Engineering 2301 and Agronomy 200, or their equivalents. Three lectures, one laboratory every other week. Time and place to be arranged. Associate Professor Black. Offered in alternate years.

An advanced course in the application of engineering principles to the problems of soil and water control in agriculture. Includes design and construction of drainage systems and farm ponds, and design and operation of sprinkler systems for irrigation.

481. AGRICULTURAL STRUCTURES

Spring term. Credit three hours. Prerequisites: Engineering 2701 and 3622, or equivalent. Lectures, T Th 11:15. Laboratory, W 2–4:25. Place to be arranged. Assistant Professor Scott. Offered in alternate years.

Synthesis of complete farmstead production units including structures, equipment, and management techniques. Integrated application of structural theory, thermodynamics, machine design, and methods engineering to satisfy biological and economic requirements.

491. LOW-COST ROADS

Credit three hours. Primarily for application to developing countries. Offered upon sufficient demand, usually in fall term. Prerequisite: consent of the instructor. Principally directed study with one two-and-a-half-hour class session per week to be arranged. Professor Spencer.

Study of economic considerations in road system improvement; road improvement planning and programming; road location and geometric design; engineering soil characteristics and classification; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces.

APPLIED MATHEMATICS*

Faculty: Ralph P. Agnew, Michael S. Balch, Henry David Block, Kenneth M. Brown, Nicholas DeClaris, Roger Farrell, Michael Fisher, Wolfgang H. J. Fuchs, Leonard Gross, Frederick Jelinek, Harry Kesten, Jack Kiefer,

* Ordinarily the minor subject for candidates whose major subject is in engineering or science should be mathematics. Applied mathematics wiill be available as a minor subject only in unusual cases when a minor in mathematics does not meet the educational objectives.

James A. Krumhansl, Simon A. Levin, G. S. S. Ludford, Anil Nerode, Lawrence E. Payne, Narahari U. Prabhu, Henri S. Sack, Edwin E. Salpeter, Duane Sather, Alfred H. Schatz, William R. Sears, A. Richard Seebass, Shan-fu Shen, Frank L. Spitzer, Benjamin Widom, Jacob Wolfowitz.

Field Representative: Lawrence E. Payne, 275 Olin Hall

MAJOR SUBJECT

Applied Mathematics

MINOR SUBJECTS. Chosen in consultation with the major advisor from those available in the biological, engineering, physical, and social sciences. One minor subject must be chosen in some area outside of mathematics and applied mathematics. Only one minor subject is required.

ADMISSION REQUIREMENTS. Graduate students from a variety of educational backgrounds, including the several branches of engineering and the physical and biological sciences as well as mathematics will be admitted to study in this Field.

LANGUAGE REQUIREMENT. A candidate for the degree of Ph.D. must demonstrate reading ability by passing an ETS examination in French, German, or Russian.

PROGRAMS OF STUDY will include advanced courses in pure mathematics, thorough grounding in mathematical methods, and studies of subject areas in which significant applications of mathematics are made.

To be admitted to the candidacy for the Ph.D. degree or to obtain a Master's degree a student must satisfy the following requirements:

A. He must be familiar with advanced calculus (Math 411–412) and elementary abstract algebra (Math 431–432).

B. He must have satisfactorily completed either Math 415–416 or Mechanics 1182–1183.

C. He must pass one of the following combinations of subjects in mathematics: *(a)* 511–512, *(b)* 521–522, *(c)* 521–531, *(d)* 511–531.

Requirement A may be met either by a satisfactory grade on the written examination administered by the Department of Mathematics in September or by taking and mastering these courses with a high degree of competence. The Admission to Candidacy Examination will consist of the final examinations in the required courses followed by an oral examination given by the candidate's committee. Normally a student will be able to satisfy these candidacy requirements at the end of his second year, but in each individual case the student's committee will decide the appropriate timing.

Each candidate for the degree must acquire familiarity with significant applications of advanced mathematics. Such applications may be studied at Cornell in several areas such as the various fields of engineering, physics, chemistry, mathematics, and computer science. The specific courses may be chosen by the student with the consent of his special committee.

The thesis in Applied Mathematics must be a mathematical contribution toward the solution of a problem arising outside mathematics.

Areas of Interest

R. P. Agnew, Professor of Mathematics: mathematical analysis.

M. S. Balch, Assistant Professor of Mathematics: methods of applied mathematics, elliptic differential equations.

H. D. Block, Professor of Theoretical and Applied Mechanics: nonlinear mechanics, automata, functional analysis.
K. M. Brown, Assistant Professor of Computer Sciences: numerical analysis.
N. DeClaris, Professor of Electrical Engineering: system theory.
R. Farrell, Associate Professor of Mathematics: probability and statistics.
M. Fisher, Professor of Mathematics and Chemistry: foundation and applications of statistical mechanics.
W. H. J. Fuchs, Professor of Mathematics: mathematical methods of physics.
L. Gross, Associate Professor of Mathematics: analysis, mathematics of quantum theory.
F. Jelinek, Assistant Professor of Electrical Engineering: information theory, coding, communication networks, automata.
H. Kesten, Professor of Mathematics: probability theory.
J. C. Kiefer, Professor of Mathematics: probability and statistics.
J. A. Krumhansl, Professor of Physics: mathematical physics, microscopic processes, and macroscopic descriptions.
S. Levin, Assistant Professor of Mathematics: mathematical analysis, partial differential equations, biomathematics.
G. S. S. Ludford, Professor of Applied Mathematics: fluid mechanics, magneto-fluid dynamics.
A. Nerode, Professor of Mathematics: mathematical logic, recursive functions and computability, algebra, automata.
L. E. Payne, Professor of Mathematics: partial differential equations.
N. U. Prabhu, Associate Professor of Operations Research: stochastic processes, queues and inventories, reliability.
H. S. Sack, Walter S. Carpenter, Jr., Professor of Engineering: engineering physics, physical properties of materials.
E. E. Salpeter, Professor of Physics and Astronomy: theoretical astrophysics, nuclear theory, statistical mechanics.
D. Sather, Assistant Professor of Mathematics: partial differential equations.
A. H. Schatz, Assistant Professor of Mathematics: partial differential equations.
W. R. Sears, J. L. Given Professor of Engineering: aerodynamics, magneto-fluid dynamics.
A. R. Seebass, Associate Professor of Aerospace Engineering: aerodynamics, magneto-fluid dynamics.
S. F. Shen, Professor of Aerospace Engineering: aerodynamics, rarefied gas-dynamics.
F. L. Spitzer, Professor of Mathematics: probability theory and analysis.
B. Widom, Professor of Chemistry: physical chemistry, statistical mechanics.
J. Wolfowitz, Professor of Mathematics: mathematical statistics, probability, and information theory.

APPLIED PHYSICS

Faculty: Neil W. Ashcroft, Peter L. Auer, Joseph M. Ballantyne, Robert W. Balluffi, Boris W. Batterman, Simon H. Bauer, John M. Blakely, K. Bingham Cady, David D. Clark, Roderick K. Clayton, Terrill A. Cool, Edmund T. Cranch, Trevor R. Cuykendall, P. C. Tobias de Boer, Lester F. Eastman, Michael E. Fisher, Thomas Gold, Paul L. Hartman, Martin O. Harwit, John P. Howe, Herbert H. Johnson, James A. Krumhansl, Che-Yu Li, Richard L. Liboff, Paul R. McIsaac, Ross McPherson, Mark S. Nelkin, Edwin L. Resler, Jr., Thor N. Rhodin, Arthur L. Ruoff, Henri S. Sack, Miriam H. Salpeter, David N. Seidman, Benjamin M. Siegel, John Silcox, Ravindra N. Sudan, Chung-Liang Tang, Anthony Taylor, Donald L. Turcotte, Watt W. Webb, George J. Wolga.

Visiting Faculty: Frank Feiner, Peter A. Egelstaff

Field Representative: Mark Nelkin, Clark Hall

MAJOR AND MINOR SUBJECT
Applied Physics

OBJECTIVES. Graduate study in the Field of Applied Physics offers the opportunity to achieve proficiency in physics, mathematics, and applied science. The course program resembles a major in Physics, and Applied Physics is particularly suitable for students preparing for a scientific career in areas of applied science based on principles and techniques of physics and in associated areas of physics. It provides a means for students with undergraduate training in physics to branch out into applied science while continuing the study of physics, and for students with backgrounds in engineering or another science to extend their knowledge of physical science principles and techniques.

A student may choose for specialization and thesis research any subject that is compatible with an approach based on the application of principles of physics and mathematics. Individual programs of study are planned to meet the needs and interests of each student, and programs involving several academic disciplines and topics that are undergoing transition from fundamental physics to applied science are readily accommodated.

Current areas of advanced study and research include: applied theoretical physics, biophysics, chemical physics, physics of fluids, nuclear and reactor physics, optics, plasma physics, radiation and matter, solid state physics and materials sciences, space physics, and surface physics.

Degree Programs

Ordinarily graduate students in Applied Physics enter in the Ph.D. Program. The Master of Science degree can also be awarded either for two years of formal course study without a thesis plus satisfactory performance on a comprehensive examination, or for a shorter program of formal study accompanied by a master's thesis.

PROFESSIONAL DEGREE

The objectives of the four-year engineering physics program are well served by an additional year of advanced study leading to the degree of Master of Engineering (Engineering Physics). The student has the opportunity to master advanced topics in physics and can extend his skill in his chosen engineering specialties. He must carry out an independent project that provides experience in defining objectives, making plans, prosecuting a program and reporting conclusions. Thus he is expected to develop and display the skills and the responsibility needed for working independently or cooperatively toward engineering goals without firmly prescribed guide lines other than his own knowledge and judgment.

From the Master's Program the student may move into development work, for example in industry, or he may go on to more advanced graduate study, either in the Field of Applied Physics or in some other related field.

Most of the laboratory facilities for research in the areas described above are made available for the student projects required for the M.Eng. degree. Each project is supervised by a member of the faculty active in the subject.

ADMISSION REQUIREMENTS FOR THE PROFESSIONAL DEGREE. (1) For Cornell students: A grade point average of 2.5 or higher in the four-year Field Program in engineering physics will allow admission without petition. (2) For transfer students: Evidence is required that the candidate has the ability and preparation to complete successfully the program of study.

REQUIREMENTS FOR THE PROFESSIONAL DEGREE. (1) An informal study, or project, of at least six credit hours value, which requires individual effort and a formal report, and which may be either experimental or analytical. (2) (a) If the project is experimental, one course in mathematics or applied mathematics; or (b) if it is analytical, one term of advanced laboratory, Physics 510, or an equivalent laboratory course to be taken upon approval by the curriculum committee of the department. (3) Physics 572, Quantum Mechanics. (4) A minimum of six hours in an engineering course sequence. (5) Chemistry 380, 596 or a new equivalent course to be arranged. (6) A seminar course — a modified version of 8252. One credit hr. or more by arrangement. (7) Technical electives to bring the total credit hours to thirty.

ADMISSION REQUIREMENTS. Undergraduate preparation in physics or other physical science or in an engineering field with strong emphasis on mathematics and modern physics provides appropriate preparation for graduate work in Applied Physics. Applications are judged with respect to evidence of quality and capability to benefit by graduate study in Applied Physics. Academic achievement in undergraduate program, technical experience, and recommendations of teachers and supervisors are carefully considered. Although not required, it is strongly suggested that Graduate Record Examination scores be submitted. The applications of students seeking to return to graduate school after a period of professional employment subsequent to their undergraduate training are welcomed.

LANGUAGE REQUIREMENT. A reading knowledge of one modern language is required for the Ph.D. degree. There is no language requirement for the M.S. degree.

Financial Aid

Graduate students in Applied Physics usually receive financial aid during their entire graduate study program provided only that they are making satisfactory progress toward an advanced degree. However, financial aid for a foreign student is not usually available his first year. Financial aid is available through fellowships, research assistantships, teaching fellowships, and tuition and fees scholarships.

For information about fellowships available through Cornell University, see pages 14–17 in this Announcement. In addition, there are several fellowships restricted to graduate students in Applied Physics.

Most students in Applied Physics hold appointments as teaching fellows or research assistants during the first and second years, and usually as research assistants during subsequent years including the period of thesis research. The initial asignments of students who begin graduate work with support as research assistants are planned to concur with their interests as closely as they can be identified.

During the summer, teaching fellows and nine-month fellowship appointees are generally appointed as research assistants, and practically all advanced graduate students have stipends either as fellows or as assistants

so that their thesis research can be pursued without interruption. Part-time teaching fellowships and summer appointments as research assistants available for fellowship students provide early teaching and research experience.

A teaching fellowship requires a total of about sixteen hours of work per week (including time for preparation and grading of papers); a research assistantship requires about twenty hours. Although a teaching fellow or a research assistant usually registers for three courses each term (instead of the possible full-time load of four courses), he is nevertheless considered to be a full-time student, earns full residence credit, and his progress toward an advanced degree is not materially impeded by his duties.

Opportunities for Advanced Study and Research

Applied theoretical physics: Quantum mechanics, statistical physics, applications of irreversible thermodynamics, cooperative phenomena, transport theory, band structures, quantum electronics, atomic basis of hydrodynamics, plasmas, superfluids, molecular theory of liquids, phase stability.

Biophysics: Electron microscopy, autoradiography, cell biology, photosynthesis, nuclear techniques in biophysics.

Chemical physics: Phase transitions, critical phenomena, chemical kinetics.

Cryogenics: Superconductivity, superfluids.

Fluid physics: Transport theory, light scattering, critical and collective phenomena, superfluids.

Nuclear and reactor physics: Low energy nuclear physics (reactions, isomers, isobaric analog states, fission), neutron physics, nuclear instrumentation (development of detectors and techniques, new applications in engineering and biology), activation analysis, reactor theory, experimental reactor physics.

Optics: Lasers, optical coherence and statistical optics, electron optics and high resolution electron microscopy, light scattering and high resolution spectroscopy, x ray and electron diffraction, scattering and imagining, nonlinear optics, optical properties of solids.

Plasma physics: Magnetohydrodynamics, solid state plasmas, shocks and fast reactions, plasma instabilities, energy conversion, controlled nuclear fusion, astrophysical plasmas.

Radiation and matter: Solid state electronics at microwave through visible frequencies, radiation damage, excited state atomic and molecular spectroscopy, x ray and electron scattering.

Solid state physics: Crystal defects, diffusion and conduction, dislocation mechanics, flow and fracture, elasticity, internal friction, electronic properties of metals, ionic crystals and semiconductors, superconductivity, ferromagnetism, electron spin resonance, high pressure properties. (For further details of programs in this area, see the description of programs of the Materials Science Center, page 42.)

Space physics: Atmospheric and ionospheric investigations, physical phenomena in astronomy and astrophysics, radio astronomy. (Further details of some programs in this area are given in the description of programs of the Center for Radiophysics and Space Research, pages 40–41.)

Surface physics: Atomistic properties of solid surfaces, interfacial phenomena in liquid and solids, physical electronic behavior, theory and application

of low energy electron diffraction and field ionization, physical properties and morphology of surface phases.

Because many of the Faculty of the Field of Applied Physics are also members of other Fields and of Research Centers, graduate students in Applied Physics can readily cross interdisciplinary boundaries and gain access to extensive research facilities. Additional details about current programs are described in bulletins available from the Field Representative for Applied Physics.

Courses of Instruction

Graduate study in Applied Physics is based on a firm knowledge of the fundamentals of physics and mathematics. Although there are no formal course requirements, this "core" program can be described in terms of the descriptions of a core course program. Because of the policy of interlocking instruction with more specialized groups the course programs are based primarily on courses administered by other fields. Thus the listings given by the appropriate fields should be consulted for course descriptions. The course program of a typical graduate student entering directly from an undergraduate major in physics is likely to be as follows:

First year, first term
- Physics 510, Advanced Experimental Physics
- Physics 561, Theoretical Physics I
- Math 415, Mathematical Methods in Physics

First year, second term
- Physics 572, Quantum Mechanics
- Physics 562, Theoretical Physics II
- Math 416, Mathematical Methods in Physics

Variations on this core program include substitution of Math 421, 422, 423 for those with weaker preparation in mathematics or inclusion of advanced undergraduate level courses in physics such as Physics 326, 356, 431, 432, 443 for those whose undergraduate preparation in physics is less extensive. Many students are also able to enter at a more advanced level or carry additional courses. Commonly included either during the first or second year are:

- Physics 574, Intermediate Quantum Mechanics
- Physics 612, Experimental Techniques in Atomic and Solid State Physics
- Physics 505–506, Design of Electronic Circuitry

Physics 510 and 574 are usually available during the summer. A common substitution is Chemistry 596, Statistical Mechanics, for Physics 562. The core program assumes that all students will extend their knowledge of quantum mechanics beyond the level of Physics 572, perhaps by study of an application of quantum mechanics in a research specialty.

Specialization at the advanced level is based on the foundation gained in these core courses. Many combinations are possible, and each program is worked out individually. However, some of the courses available in various typical specializations are listed below. This list is not comprehensive, and offerings listed in other fields should be consulted for other topics and for course descriptions.

Nuclear physics
- Physics 645. Nuclear Physics
- Physics 574. Intermediate Quantum Mechanics

Physics 657. Theory of Nuclei
Engineering 8309. Low-Energy Nuclear Physics
Engineering 8312. Nuclear Reactor Theory
Engineering 8313. Reactor Theory II
Engineering 8314. Neutron Transport Theory
Engineering 8351. Nuclear Measurements Laboratory
Engineering 8352. Advanced Nuclear and Reactor Laboratory
Engineering 8333. Nuclear Reactor Engineering
Engineering 8336. Nuclear Materials

Plasma physics

Magnetohydrodynamics
Engineering 7201 and 7202. Magnetohydrodynamics I and II
Engineering 7203. Advanced Topics in Plasma-Dynamics I
Engineering 4565 and 4566. Radiophysics of the Atmosphere I and II

Theoretical plasma physics
Engineering 4561 and 4562. Plasma Physics I and II
Engineering 4661. Kinetic Equations
Engineering 4662. Kinetic Theory of Plasma

High temperature molecular physics
Engineering 7101 and 7102. Advanced Kinetic Theory; Gasdynamics
Chemistry 580. Kinetics of Chemical Reactions
Chemistry 598. Selected Topics in Physical Chemistry
Engineering 7103. Dynamics of Rarefied Gases

Astrophysical plasmas
Astronomy 520 and 521. Radio Astronomy I and II
Astronomy 524. Radio Waves in Ionized Gases
Astronomy 532. Physics of the Magnetosphere
Astronomy 560. Theory of Stellar Structure and Evolution

Quantum electronics
Engineering 4511. Electrodynamics
Engineering 4514. Microwave Theory
Engineering 4520. Graduate Laboratory
Engineering 4531 and 4532. Quantum Electronics I and II
Engineering 4535 and 4536. Semiconductor Devices I and II
Engineering 4538. Electromagnetic Properties of Solids
Engineering 4631. Advanced Microwave Electronics

Solid state physics and materials science
Physics 635. Solid State Physics
Physics 636. Advanced Solid State Physics
Physics 654. Theory of Many-Particle Systems
Physics 680. Special Topics in Solid State Physics
Engineering 4531 and 4532. Quantum Electronics I and II
Engineering 4538. Electromagnetic Properties of Solids
Engineering 6601. Topics in Thermodynamics and Kinetics
Engineering 6602. Phase Transformations
Engineering 6603. Crystal Mechanics
Engineering 6604. Dislocations
Engineering 6605. Electrical and Magnetic Properties of Engineering Materials
Engineering 6606. Mechanical Behavior of Materials
Engineering 6611. Principles of Diffraction
Engineering 6762. Physics of Solid Surfaces

Engineering 6872. Nuclear Materials
Chemistry 578. Thermodynamics
Chemistry 580. Kinetics of Chemical Reactions
Chemistry 589. X Ray Crystallography
Chemistry 594. Quantum Mechanics II

Space physics
Engineering 4561 and 4562. Plasma Physics I and II
Engineering 4565 and 4566. Radiophysics of the Atmosphere I and II
Engineering 4567 and 4568. Advanced Antenna Methods and Problems I and II
Astronomy 431. Introduction to Astrophysics
Astronomy 432. Introduction to Space Physics
Astronomy 510. Cosmology and Evolution
Astronomy 520 and 521. Radio Astronomy I and II
Astronomy 524. Radio Waves in Ionized Gases
Astronomy 531. Cosmic Rays
Astronomy 532. Physics of the Magnetosphere
Astronomy 560. Theory of Stellar Structure and Evolution

Courses Administered by Applied Physics

Courses at the advanced undergraduate and graduate level administered by Applied Physics and not listed elsewhere in the Graduate School Announcement are listed below.

EP 8121. THERMODYNAMICS AND FLUID MECHANICS

Credit three hrs. Fall term.

Classical thermodynamics and applications, compressible one-dimensional flows and shock waves; introduction to fluid mechanics. The general level of sophistication expected in 8121–8122 is that of the fourth-year student in engineering physics.

EP 8122. STATISTICAL MECHANICS AND KINETIC THEORY

Credit three hrs. Spring term. Prerequisite: 8121 or its equivalent.

Ensembles and partition functions, ideal quantum and classical gases, imperfect gases, distribution and correlation functions. Random walks and Brownian motion, fluctuations, kinetic theory. At the level of F. Reif, *Fundamentals of Statistical and Thermal Physics.*

EP 8133. MECHANICS OF PARTICLES AND SOLID BODIES

Credit three hrs. Fall term. Three recitations.

Newton's laws, harmonic oscillator. Fourier series and Green's function solutions. Lagrange equations, Hamiltonian formalism, Central force motion, orbits, scattering, cross-sections. Many particle dynamics, Lagrangian formulations, Lorentz transformation.

EP 8134. MECHANICS OF CONTINUA

Credit three hrs. Spring term. Three recitations.

Mechanics of continua, equilibrium, propagation of sound waves. Elasticity, torsion, shear, bending stresses.

EP 8205. ELECTRICAL AND MAGNETIC PROPERTIES OF ENGINEERING MATERIALS

Credit three hrs. Fall term. Prerequisite: Physics 454 or consent of the instructor.

Electrical properties of semiconductors. Metallic alloys. Ferromagnetic materials. Superconductivity. Optical and dielectric properties of insulators and semiconductors. At the level of Kittel, *Introduction to Solid State Physics;* Chikazumi, *Physics of Magnetism;* Lynton, *Superconductivity;* Livingston and Schadler, *The Effect of Metallurgical Variables on Superconductivity Properties.*

EP 8211. PRINCIPLES OF DIFFRACTION

Credit three hrs. Fall term. Offered jointly with the Department of Materials Science and Engineering.

Production of neutrons, x rays, absorption, scattering, Compton effect. Diffraction from periodic lattices, crystal symmetry, single crystal and powder techniques. Fourier methods, thermal vibration and scattering, diffraction from liquids and gases, introduction to dynamical diffraction of x rays and electronics, extinction phenomena and perfect crystals. Selected experiments in diffraction.

EP 8212. SELECTED TOPICS IN DIFFRACTION

Credit three hrs. Spring term. Three lectures. Prerequisite: 8211. Offered jointly with the Department of Materials Science and Engineering.

Dynamical diffraction: Ewald-von Laue theory of dynamical diffraction applied to x rays and electrons. Currently developing theory and application to defects in solids. Phenomena investigated via diffuse scattering: phonons, measurement of dispersion curves, frequency spectrum, Debye temperatures, vibrational amplitudes. Order-disorder phenomena: short and long-range order, Guinier-Preston zones. Selected topics of current interest related to x ray, neutron, and electron diffraction, with contributions from several members of the faculty.

EP 8252. SELECTED TOPICS IN PHYSICS OF ENGINEERING MATERIALS

Credit one hr. Fall term. Primarily for candidates for Master of Engineering (Engineering Physics); others with consent of the instructor.

Seminar-type discussion of special topics in the field of engineering materials, such as plastic and rheological properties; dielectric and magnetic behavior; semiconductors; radiation damage, etc. Emphasis is given to the interpretation of the phenomena in light of modern theories in physics of solids and liquids and their impact on the engineering applications. Current literature is included in the assignments.

EP 8262. PHYSICS OF SOLID SURFACES

Credit three hrs. Spring term. A lecture course for graduate students and upperclassmen offered jointly with the Department of Materials Science and Engineering.

An introductory critical review of advances in the theory of the solid-state related directly to surface phenomena. Thermodynamics of surface phases, atomistic theory of surfaces and dynamics of interaction of electrons, ions and atoms with surfaces are considered. Reference is made to application of the theory to surface and interface phenomena in metals, insulators and semiconductors as much as possible. Presented at the level of *Advances in Solid State Physics,* Ed., Seitz and Turnbull.

EP 8601. PHYSICAL APPROACHES TO PROBLEMS OF PHOTOSYNTHESIS

Credit three hrs. Fall term. Given in alternate years. Prerequisites: Chemistry 104 or 108, Mathematics 112, Physics 208, or permission of the instructor.

Emphasis is on physical and photochemical mechanisms and physical experimental approaches. Photosynthetic organisms; their photochemical apparatus, metabolic pathways, and mechanisms for energy conversion. Descriptive introduction to the physics of excited states in molecules and molecular aggregates. Optical and photochemical properties of chlorophyll, and of the living photosynthetic tissue. Contemporary investigations of the photosynthetic mechanism. The level of the course can be judged by consulting R. K. Clayton, *Molecular Physics in Photosynthesis* (Waltham: Blaisdell Publishing Co., 1965.)

EP 8603. GENERAL PHOTOBIOLOGY

Credit three hrs. Fall term. Prerequisites: Chemistry 104 or 108, Mathematics 112, Physics 208, or the permission of the instructor. Given in alternate years.

A survey of systems of current interest in photobiology, including photosynthesis, bioluminescence, vision, photoperiodism, and the action of ultraviolet on nucleic acids. Physical concepts and methodologies are emphasized.

ASTRONOMY AND SPACE SCIENCES

Faculty: Ralph Bolgiano, John P. Delvaille, Frank D. Drake, Thomas Gold, Kenneth I. Greisen, Martin Harwit, Frederick Jelinek, Richard L. Liboff, Edwin L. Resler, Jr., Henri S. Sack, Edwin E. Salpeter, R. William Shaw, Ravindra N. Sudan.

Visiting Professor: Cyril Hazard

Field Representative: Martin Harwit, 212 Space Science Building.

MAJOR AND MINOR SUBJECTS

Astronomy
Astrophysics
Magnetohydrodynamics
Radiophysics
Space Sciences (General)

There is no language requirement for the Master's degree. The language requirement for the Ph.D. degree consists of proficiency in one of the following: French, German, or Russian.

The major and both minor subjects for the doctorate should not all be chosen in this Field.

Students may come to this Field with a strong background in astronomy, electrical engineering, engineering physics, mathematics, or physics.

Members of the staff are particularly interested in directing graduate research in the following subjects:

Astronomy and astrophysics: cosmic rays, cosmology, dynamics of the interstellar gas, geodetic astronomy, lunar photometry, solar system magnetohydrodynamics, stellar spectroscopy, theory of stellar structure, stellar evolution, nuclear processes in stars, stellar statistics.

Atmospheric and ionospheric radio investigations: dynamics of the atmosphere and ionosphere; incoherent electron scattering; study of refraction, scattering, attenuation due to the inhomogeneous nature of the troposphere and ionosphere; theory and observation of propagation of radio waves in ionized media such as the ionosphere.

Radio astronomy: distribution and classification of radio sources, radar investigations of the moon and planets, solar radio observations; studies of gaseous nebulae.

Space vehicle instrumentation: instrumentation relating to lunar exploration, magnetic field measurements, tenuous gas and particle flux measurements; infrared observations from rockets.

Graduate students in this Field may be connected with the Cornell University Center for Radiophysics and Space Research. Many members of the faculty listed above are members of this Center, which possesses or is planning important facilities for geophysical and solar system investigations both by radio methods and by space vehicle instrumentation. Further details of this organization and facilities can be obtained by writing to the Secretary, Cornell University Center for Radiophysics and Space Research, Space Science Building. See also pages 40–41.

The recently formed Cornell-Sydney University Astronomy Center, an international cooperative venture in the field of astronomy and space sciences, provides students and faculty members of the two universities with an opportunity to work together in the field. The Sydney University facilities include the Criss-Cross and Mills Cross radio telescopes, the stellar intensity interferometer, detectors for very high energy cosmic rays, and plasma and nuclear physics laboratories. Further details can be obtained by writing to the Secretary, Astronomy Department, Space Science Building. See also page 41.

Courses

431. INTRODUCTION TO ASTROPHYSICS

Fall term. Credit three hours. Prerequisites: Physics 225, 226, and 303 or the equivalent. Mr. Harwit. M W F 10:10.

Dynamics of planetary and stellar systems. Stellar structure and evolution. Binary, variable and peculiar stars. Nuclear synthesis in stars. Stellar atmospheres. Abundance of the chemical elements.

432. INTRODUCTION TO SPACE PHYSICS

Spring term. Credit three hours. Prerequisite: Astronomy 431 or consent of the instructor. Mr. Harwit. M W F 10:10.

Interstellar dust and gas. Evolution of the Stromgren sphere. Star formation. Interstellar magnetic fields, cosmic rays and radio emission. Interplanetary gas and dust. Comets, meteorites, and micrometeorites.

510. COSMOLOGY AND EVOLUTION

Spring term. Credit three hours. Offered on sufficient demand. Open to graduate students with the consent of the instructor. Hours to be arranged. Messrs. Gold and Harwit.

Relativistic astrophysics. Cosmological models and tests of models. Evolution of stars and galaxies. Quasars.

520. RADIO ASTRONOMY I

Fall term. Credit three hours. Prerequisite: Astronomy 330, or graduate status, or consent of the instructor. Hours to be arranged. Mr. Drake.

Radio astronomy telescopes and electronics. Preferred observing procedures and data analysis. Concepts of aperture synthesis. Physical mechanisms of radio emission. Radio and radar studies of the solar system. Physical nature of the sun, moon, and planets as deduced from radio sources.

521. RADIO ASTRONOMY II

Spring term. Credit three hours. Prerequisite: Astronomy 520. Hours to be arranged. Mr. Drake.

Thermal and nonthermal radiation from the galaxy. Supernova remnants. Relation of galactic emission to cosmic rays. Galactic 21-cm. emission. Galactic structure and kinematics as inferred from radio observations. Radio emission from normal and abnormal galaxies. Quasi-stellar radio sources. Physical theories of the quasi-stellar sources and abnormal radio galaxies.

524. RADIO WAVES IN IONIZED GASES

Spring term. Credit three hours. Prerequisite: Astronomy 520 or consent of the instructor. Hours to be arranged. Staff.

Propagation of radio waves in inhomogeneous plasma. Scattering by irregularities. Generation and absorption of radio waves. Scintillations. Applications to the theory of radio emission by the sun and by Jupiter.

531. COSMIC RAYS

Fall term. Credit three hours. Prerequisite: consent of the instructor. Hours to be arranged. Staff. Given in alternate years.

Motion of high energy particles through interstellar and interplanetary space. Solar particles and Sun-Earth relations. Intensity time variations. Cosmic rays in the geomagnetic field. Cosmic rays in the galaxy. The origin of cosmic rays.

532. PHYSICS OF THE MAGNETOSPHERE

Spring term. Credit three hours. Prerequisite: consent of the instructor. Hours to be arranged. Staff. Given in alternate years.

Interaction between charged and neutral components of the ionosphere. Tidal theory of regular magnetic variations. Equatorial anomaly. Sporadic E. Structure and composition of the ionosphere. VLF and ELF emissions. Radiation belts. Aurora. Magnetic storms.

540. ADVANCED STUDY AND RESEARCH

Either term. Credit one to four hours a term. Prerequisites: advanced standing in astronomy and consent of the instructor. Staff.

Upon sufficient demand, seminars will be arranged from time to time in topics not currently covered in regular courses. Typical seminar subjects are high energy particles in astronomy, planetary and lunar physics, geophysics.

560. THEORY OF STELLAR STRUCTURE AND EVOLUTION

Fall term. Credit three hours. Prerequisite: graduate status with good physics background. Given upon sufficient demand (usually in alternate years). Time to be arranged. Staff.

Summary of observational facts. Dimensional analysis. Nuclear reactions in stars. Models for static and evolving stars. Very massive objects and general relativity. White dwarfs and neutron stars.

CHEMICAL ENGINEERING

Faculty: George G. Cocks, Victor H. Edwards, Robert K. Finn, Peter Harriott, Jay E. Hedrick, Jean P. Leinroth, Jr., Ferdinand Rodriguez, George F. Scheele, Julian C. Smith, Raymond G. Thorpe, Robert L. Von Berg, Herbert F. Wiegandt, Charles C. Winding, Robert York.

Field Representative: Charles C. Winding, 124 Olin Hall.

MAJOR AND MINOR SUBJECTS

Biochemical Engineering
Chemical Engineering, General
Chemical Processes and Process Control
Materials Engineering
Nuclear Process Engineering

To qualify for admission, a student must have completed satisfactorily the equivalent of the fundamental work required by an accredited curriculum in chemical engineering. Outstanding students who have received a baccalaureate degree with a major in chemistry will also be considered for admission. Normally an extra year of residence is required of such students to make up work in engineering fundamentals.

A student in a Ph.D. program must demonstrate reading ability in one foreign language chosen from French, German, or Russian. There is no language requirement for the M.S. degree.

"Chemical Engineering, General" is required of all students, either as a major or as a minor. Ph.D. candidates are required to select one minor within the Field and one minor outside the Field. M.S. candidates may choose a minor which can be within or outside the Field. Each M.S. candidate must pass an oral examination on his major and minor subjects and on his thesis. Two examinations are required before a student is designated as a Ph.D. candidate. On recommendation of the faculty, a student will be admitted to the written Field examination. When this examination has been passed to the satisfaction of the faculty of the Field, the student takes an oral comprehensive Admission to Candidacy Examination administered by his Special Committee. After the thesis has been completed, an oral Final Examination, administered by the Special Committee and covering the thesis and related topics, must be taken.

Candidates are expected to pursue a course of study and research that will give them a deeper comprehension of the basic and applied sciences and will develop initiative, originality, and creative ability. To achieve this goal the student participates in graduate courses and seminars and must complete an original, individual investigation for a thesis. Theses may involve either experimental research or special projects in such subjects as design, economics, and mathematical analysis. Specific programs are planned to fit the objectives of the student and to develop original thinking. An arbitrarily fixed series of courses is not required, but each student is expected to acquire a strong background in applied mathematics, chemical processes, rate and mass transfer processes, reaction kinetics, and thermodynamics. Outside minor subjects may be chosen from a wide variety of other Fields consistent with the student's objectives.

Research Opportunities

Fluid dynamics, heat transfer, mass transfer, reaction kinetics, stage processes, and thermodynamics may be regarded as the fundamentals of chemical engineering. The Cornell staff is actively working on or has interests in many such projects. Although particular projects actively in progress are continually changing, some recent, specific research interests of particular staff members are:

George G. Cocks: microscopy, properties of materials, solid state chemistry, crystallography.

Victor H. Edwards: kinetics and process control in fermentation.

Robert K. Finn: continuous fermentation, agitation and aeration, processing biochemicals, electrophoresis, microbial conversion of hydrocarbons.

Peter Harriott: chemical kinetics and reactor design, process control, diffusion in membranes and porous solids.

Jay E. Hedrick: economic analyses and forecasts.

Jean P. Leinroth: adsorption, residence time distribution, chemical process development.

Ferdinand Rodriguez: non-Newtonian flow, Redox reactions, electrical and mechanical properties of polymer systems, rheological phenomena.

George F. Scheele: hydrodynamic stability, effect of heat transfer on flow fields.

Julian C. Smith: conductive transfer processes, flow of granual solids, heat transfer, mixing.

Raymond G. Thorpe: phase equilibria, fluid flow, kinetics of polymerization.

Robert L. Von Berg: liquid-liquid extraction, reaction kinetics, effect of radiation on chemical reactions.

Herbert F. Wiegandt: crystallization petroleum processing, saline water conversion, direct contact heat transfer.

Charles G. Winding: degradation of polymers, polymer compounding, filler-polymer systems, differential thermal analysis.

Robert York: mass transfer, diffusion, thermodynamic properties, production of shale oil, chemical market analyses.

Professional Degree

The Master of Engineering degree is the only professional engineering degree offered by Cornell University to presently entering students.

Admission to the Master of Engineering (Chemical) degree program is open to persons who have been granted a Bachelor's degree or the equivalent, and whose background indicates that they can profitably study the advanced courses offered by the School of Chemical Engineering. The purpose of this program is to offer study in depth in both comprehensive and specialized chemical engineering subjects and to prepare students for professional careers in advanced engineering practice.

Courses

5105. ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS

Credit three hours. Spring. Three lectures. Mr. Von Berg.

Application of the general thermodynamics method to advanced problems in chemical engineering. Evaluation, estimation, and correlation of properties. Chemical and phase equilibria.

5106. REACTION KINETICS AND REACTOR DESIGN

Credit three hours. Fall. Three lectures. Mr. Von Berg.

A study of chemical reaction kinetics and principles of reactor design for chemical processes.

5107. ADVANCED REACTION KINETICS

Credit three hours. Fall. Three lectures. Mr. Harriott.

Effects of heat transfer, diffusion, and nonideal flow on reactor performance. Optimum design for complex reactions. Analysis of current literature on topics such as partial oxidation, catalytic cracking, hydrogenation, and polymerization.

5108. COLLOIDAL AND SURFACE PHENOMENA

Credit three hours. Fall. Mr. Finn.

Lectures, demonstrations, and problems in the physics and chemistry of small particles and surface films. Topics include surface energy, surface films, electrokinetics, and colloidal behavior.

5161. PHASE EQUILIBRIA

Credit three hours. Fall. Three lectures. Mr. Thorpe.

A detailed study of the pressure-temperature-composition-relations in binary and multicomponent heterogeneous systems where several phases are of variable composition. Prediction of phase data.

5205. CHEMICAL PROCESS SEMINAR

Credit two hours. Fall. Mr. Wiegandt.

A discussion of recent advances in chemical process development.

5505, 5506. ADVANCED TRANSPORT PHENOMENA

Credit four hours each term. Fall, spring. Messrs. Scheele and Smith.

An integrated treatment of momentum, mass and heat transfer. Molecular transport; the equations of change; viscous laminar flow of Newtonian and non-Newtonian fluids; perfect fluid theory; boundary layer theory; unsteady-state transfer; penetration theory models of mass and heat transfer; flow stability; turbulent transport; simultaneous heat and mass transfer; applications to industrial operations.

5605, 5606, 5607, 5608. DESIGN PROJECTS

Credit variable. Fall and spring. Staff.

Individual projects involving the design of chemical processes and plants. Estimation of costs of construction and operation, variation of costs and profits with rate of production, etc.

5609. ANALYSIS AND DESIGN OF PROCESS EQUIPMENT

Credit three hours. Fall. Mr. Smith.

Discussion and analysis of operating principles, design, and selection of chemical process equipment.

5621. PROCESS DESIGN AND ECONOMICS

Credit six hours. Fall. Mr. York.

Methods for estimating capital and operating costs. Performances, selection, design, and cost of process equipment. Process development and design. Market research and surveys.

5622. PROCESS AND PLANT DESIGN

Credit six hours. Continuation of 5621. Mr. York.

Process design, including reactors, process equipment, and separating systems. Layout and model of process units. Plant location, design, and layout. Cost estimates and project evaluation; equivalent interest rate of return and discounted cash flow.

5631. SEPARATION PROCESSES

Credit three hours. Fall.

Problems involving the optimum design of equipment for the physical separation of chemical mixtures. Primarily for graduate students.

5632. PROCESS EVALUATION AND DESIGN

Credit four hours. Spring.

Techniques and case studies in evaluating chemical processes. Cost estimation for processes, equipment, and plant.

5635. MARKETING OF CHEMICAL PRODUCTS

Credit three hours. Fall. Three lectures. Mr. Hedrick.

Examination of marketing activities, organizations, and costs in the distribution of chemicals. A market research project is required.

5636. ECONOMICS OF THE CHEMICAL ENTERPRISE

Credit three hours. Spring. Three lectures. Mr. Hedrick.

Research economics; feasibility studies; information services; venture analysis; depreciation and amortization; planning.

5641. INVENTIONS, PATENTS, AND TRADE SECRETS

Credit three hours. Fall. Mr. York.

Protection of inventions and trade secrets. Statutory and other legal requirements for patentability of inventions. Evaluation of patents. Role and management of patents in planning growth and expansion.

5642. DEVELOPMENT ECONOMICS

Credit three hours. Spring. Mr. York.

Planning, evaluation, and management of development activities in the process industries as related to research, processing, new products, markets, and long-range growth.

5717. PROCESS CONTROL

Credit three hours. Spring. Two lectures, one laboratory. Mr. Harriott.

Dynamic response of processes and control instruments. Use of frequency response analysis, Laplace transforms, and electronic analogs to predict the behavior of feedback control systems.

5741. PETROLEUM REFINING

Credit three hours. Spring. Three lectures. Mr. Wiegandt.

A critical analysis of the processes employed in petroleum refining.

5742. POLYMERIC MATERIALS

Credit three hours. Fall. Three lectures. Mr. Rodriguez.

Chemistry of polymerization reactions, manufacture and properties of synthetic resins, fibers, plastics, and rubbers.

5743. PROPERTIES OF POLYMERIC MATERIALS

Credit three hours. Spring. Prerequisite: 5742. Mr. Rodriguez.

Mechanical, electrical, and optical properties of polymers. Phenomenological aspects and molecular theories of non-Newtonian flow viscoelasticity and ultimate tensile properties.

5745. ANALYSIS OF POLYMERIC PROCESSES

Credit three hours. Fall. Three lectures. Prerequisite: 5742. Mr. Hedrick.

Technical and economic evaluations of the principal processes used in manufacture of resins, plastics, and elastomers, including analyses of raw materials, reactor systems, product preparation, and problems in distribution and marketing.

5746. CASE STUDIES IN THE COMMERCIAL DEVELOPMENT OF CHEMICAL PRODUCTS

Credit three hours. Spring. Three lectures. Mr. Hedrick.

Detailed analysis of specific cases involving the development of new chemical products. Particular emphasis is given to planning activities, research justification, and market forecasting. Profitability calculations and projections are required.

5748. FERMENTATION ENGINEERING

Credit three hours. Spring. Two lectures, one recitation. Mr. Finn.

An advanced discussion of fermentation as a unit process. Topics include sterilization, aeration, agitation, and continuous fermentation.

5749. INDUSTRIAL MICROORGANISMS

Credit one hour. Fall. One lecture. Mr. Finn.

A brief introductory course in microbiology for students with a good background in chemistry.

5752. POLYMERIC MATERIALS LABORATORY

Credit two hours. Fall. One laboratory. Prerequisite: 5742. Mr. Rodriguez.

Experiments in the formation, characterization, fabrication, and testing of polymers.

5760. NUCLEAR AND REACTOR ENGINEERING

Credit two hours. Spring. Two lectures. Mr. Von Berg.

Fuel processing and isotope separation, radioactive waste disposal, fuel cycles, radiation damage, biological effects and hazards, shielding power reactors.

5859. ADVANCED CHEMICAL MICROSCOPY

Credit variable. Offered on demand either term. Mr. Cocks.

Laboratory practice in special methods and special applications of chemical microscopy.

5900. SEMINAR

Credit one hour. Fall, spring.

General chemical engineering seminar required of all graduate students majoring in the Field of Chemical Engineering.

5903. SEMINAR IN BIOCHEMICAL ENGINEERING

Credit one hour. Spring. Messrs. Edwards and Finn.

Advanced topics in the engineering applications of biophysics and biochemistry. Discussion of current research in the field.

5909. RESEARCH SEMINAR

Spring. One lecture. Mr. Winding.

Required of all students enrolled in the predoctoral honors program. An introduction to the research methods and techniques of chemical engineering.

5952, 5953, 5954. RESEARCH PROJECT

Credit three hours; additional credit by special permission. Fall, spring. Staff.
Research on an original problem in chemical engineering.

5955, 5956. SPECIAL PROJECTS IN CHEMICAL ENGINEERING

Credit variable. Either term. Staff.
Research or studies on special problems in chemical engineering.

CHEMISTRY

Faculty: Andreas C. Albrecht, Simon H. Bauer, Alfred T. Blomquist, James M. Burlitch, Richard A. Caldwell, W. Donald Cooke, Vincent du Vigneaud, Manfred Eigen, Elliot Ellson, Robert C. Fay, Michael E. Fisher, Jack H. Freed, David H. Geske, Melvin J. Goldstein, Gordon G. Hammes, J. L. Hoard, Roald Hoffmann, Robert E. Hughes, Edward Kostiner, Franklin A. Long, Jerrold Meinwald, William T. Miller, George H. Morrison, Hans Muxfeldt, Robert A. Plane, Richard F. Porter, Harold A. Scheraga, Martin F. Semmelhack, Michell J. Sienko, David A. Usher, Benjamin Widom, Charles F. Wilcox, Jr., J. J. Zuckerman.

Field Representative: Charles F. Wilcox, Jr., 312 R Chemistry Research Building.

MAJOR AND MINOR SUBJECTS

Analytical Chemistry
Bio-organic Chemistry
Biophysical Chemistry
Inorganic Chemistry
Organic Chemistry
Physical Chemistry
Theoretical Chemistry

Language requirement for the Master's degree: none. Language requirement for the Ph.D. degree: proficiency in German or, with permission of student's Special Committee, Russian.

The program of graduate study in the Field of Chemistry is designed to give a broad training in the fundamental knowledge of chemistry and in methods of research. A graduate student will ordinarily pursue these objectives by taking advanced courses, by participation in organized and informal seminars and discussions with his associates and faculty members, and by carrying out and reporting on a research project in his major subject. Special opportunities are provided by (1) the Materials Science Center at Cornell, which supports several research assistantships for graduate students in chemistry, and (2) a National Institutes of Health Training Grant which similarly provides trainee stipends for work in bio-organic and biophysical chemistry. Upon completion of their study program, graduates normally go out to positions in research laboratories or to positions involving teaching and research.

Candidates for the degree of Master of Science or Doctor of Philosophy with a major in chemistry will be expected to offer for admission the equivalent of an A.B. degree with a major in chemistry. Such training should include courses in general chemistry, mathematics, organic chemistry, physical chemistry, physics, and qualitative and quantitative analysis. Some experience with foreign languages, preferably German and either French or Russian, is also regarded as essential. In admitting students, emphasis is placed on quality of performance and promise for research as judged by those best acquainted with applicants. Unusually promising students may be admitted with deficiencies in undergraduate training. In such cases, work designed to make up

the deficiencies will be required, and more than the usual period of residence may be necessary.

Proficiency tests will be required of all entering candidates for advanced degrees (M.S. or Ph.D.) with a major in chemistry. These tests are given a few days before registration for the fall term and cover the divisions of analytical, inorganic, organic, and physical chemistry. Each test will be about two and one-half hours in length and will cover material normally presented in elementary courses in the subjects listed above. The results of these tests will be used to aid the student's Special Committee in the planning of his program of study. While the results will not be considered in the usual sense of "passing" or "failing," low marks in one or more of the tests may require enrollment in elementary courses.

Graduate students are encouraged to carry on research during the summer, and a number of Summer Research fellowships are available for this purpose.

Graduate students are required to register with the Department of Chemistry on the registration days at the beginning of each term. Entering students will consult with the Chairman of the Department and with professors composing their temporary Special Committees.

In addition to the courses in chemistry, attention is directed to courses in biochemistry, chemical engineering, and mathematics and physics.

A graduate student who desires to take a minor subject in Chemistry with a major subject from some Field other than Chemistry will be required to offer or acquire a satisfactory background for advanced work. This will ordinarily consist of an introductory course in general chemistry and of intermediate courses prerequisite to advanced work in the minor subject in Chemistry. The work in his minor subject in Chemistry comprises advanced study planned with the approval of his Special Committee.

Specific inquiries from prospective graduate students are welcomed and should be addressed to the Field Representative or to any member of the faculty. Applications for teaching fellowships or research assistantships should be addressed to the Field Representative of the Department of Chemistry, Baker Laboratory. A brochure entitled *Graduate Work in Chemistry at Cornell* is available from the Field Representative.

Courses

411. INORGANIC CHEMISTRY LABORATORY

Fall term. Credit four hours. Prerequisite or parallel course: Chemistry 387, or consent of the instructor. Hours to be arranged. Mr. Zuckerman.

Laboratory experiments illustrating the techniques and scope of modern inorganic chemistry.

421. INTRODUCTION TO INORGANIC RESEARCH

Either term. Credit two or four hours. Prerequisites: Chemistry 387–388 or 285–286 at an average of 80 or better, and consent of the instructor. Hours to be arranged. Messrs. Burlitch, Fay, Kostiner, Plane, Porter, Sienko, and Zuckerman.

Informal advanced laboratory and library work, planned individually in consultation with a staff member, involving the preparation and characterization of inorganic substances. A written report is required.

426. INSTRUMENTAL ANALYSIS

Spring term. Credit four hours. Prerequisite: Chemistry 285 or 387 or consent of the instructor. Enrollment is limited. Laboratory may be taken separately

by graduate students. Lectures, T Th 10:10. Discussion period to be arranged. Laboratory, one afternoon a week, to be arranged. Mr. Gulick and assistants.

A discussion of the broad aspects of modern analytical chemistry, including opticometric, electrometric, nuclear, and mass spectrometric methods.

433. INTRODUCTION TO ANALYTICAL RESEARCH

Either term. Credit two or four hours. Prerequisite: Chemistry 388 with an average of B— or better or consent of the instructor. Hours to be arranged. Messrs. Cooke, Geske, and Morrison.

Informal research in the Field of Analytical Chemistry involving both laboratory and library work.

456. IDENTIFICATION OF ORGANIC COMPOUNDS

Spring term. Credit two hours. Prerequisite: Chemistry 358. Enrollment is limited; registrants who do not appear at the first meeting of their section will forfeit their registration. Discussion-laboratory, M W 1:25–4:25; T Th 8–11; T Th 1:25–4:25; or F 1:25–4:25 and S 8–11. Scheduled preliminary examinations may be held in the evenings.

A laboratory course designed to illustrate both classical and spectroscopic methods for determining the structures of organic compounds.

457. ADVANCED ORGANIC-ANALYTICAL LABORATORY

Spring term. Credit four hours. Primarily for seniors and graduate students in chemistry. Prerequisites: Chemistry 358 and Chemistry 426, or Chemistry 525, or consent of the instructor. Discussion, T Th 8. Laboratory, three of the following periods: T Th 8–11, M T W Th F 1:25–4:25, S 10:10–1:10.

Laboratory problems illustrating the applications of instrumental analytical techniques to organic research.

461. INTRODUCTION TO ORGANIC RESEARCH

Either term. Credit two to four hours. Prerequisites: 456 or 457 and consent of the instructor. Primarily for seniors and graduate students as preparation for advanced and independent work. Enrollment limited for undergraduates to those having a record of B— or better in prerequisite courses. Laboratory and weekly discussion meeting: hours to be arranged. Messrs. Blomquist, Caldwell, Goldstein, Meinwald, Miller, Muxfeldt, Semmelhack, Usher, and Wilcox.

465–466. ORGANIC CHEMISTRY

Throughout the year. Credit four hours a term. Prerequisite: Chemistry 358. Chemistry 465 is prerequisite to 466. Primarily for juniors, seniors, and graduate students. Enrollment limited for undergraduates to those having a record of B— or better in previous courses in organic chemistry. Lectures, M W F 12:20. Discussion, to be arranged. Fall term, Mr. Wilcox; spring term, Mr. Muxfeldt.

Fall term: structural theory; resonance; methods of structure determination; conformational analysis and other aspects of stereo-chemistry; introduction to reaction mechanisms; synthesis and characteristic reactions of hydrocarbons. Spring term: synthesis and reactions of the principal classes of organic compounds, with an emphasis on newer developments; the application of mechanistic reasoning to synthetic problems; multi-step syntheses.

[474. PHYSICAL CHEMISTRY OF HIGH POLYMERS]

Spring term. Credit four hours. Prerequisite: Chemistry 286 or 388 or consent of the instructor. Primarily for graduate students. Lectures, T Th 8, S 9:05. Not offered in 1967–1968.

477. INTRODUCTION TO RESEARCH IN PHYSICAL CHEMISTRY

Credit two to four hours. Prerequisites: Chemistry 388 at an average of B— or better and consent of the instructor. Hours to be arranged. Messrs. Albrecht, Bauer, Fisher, Freed, Hammes, Hoard, Hoffmann, Hughes, Long, Porter, Scheraga, and Widom.

Informal advanced laboratory and library work in physical chemistry, planned individually in consultation with a staff member.

481. ADVANCED PHYSICAL CHEMISTRY

Fall term. Credit four hours. Prerequisite: Chemistry 286 or 388. Lecture: M W F 9:05. Discussion section to be arranged. Mr. Widom.

A discussion of advanced topics in physical chemistry, including an introduction to the principles of quantum theory and statistical mechanics, atomic and molecular spectra, and elementary valence theory.

505–506. ADVANCED INORGANIC CHEMISTRY

Throughout the year. Credit four hours a term. Prerequisite or parallel course: Chemistry 387–388 or 285–286, or consent of the instructor. Chemistry 505 is prerequisite to Chemistry 506. Open to juniors, seniors, and graduate students. Lectures, M W F 11:15. Fall term, instructor to be announced; spring term, Mr. Sienko.

Theories of atomic structure and chemical bonding are applied systematically to the elements as they appear in the Periodic System, with emphasis on the stereochemistry of inorganic substances.

515–516. SELECTED TOPICS IN ADVANCED INORGANIC CHEMISTRY

Throughout the year. Credit two hours a term. Students may register for either term separately. Prerequisite: Chemistry 388. Lectures, T Th 12:20. Messrs. Burlitch and Fay.

Detailed consideration is given each term to one or two special topics selected from the field of theoretical and experimental inorganic chemistry. Topics are varied from year to year.

525. ADVANCED ANALYTICAL CHEMISTRY

Fall term. Credit four hours. Prerequisite: Chemistry 286 or 388. For graduate students only except by consent of the instructor. Lectures, M W F 8. Examinations, T 7:30 P.M. Mr. Cooke.

The application of molecular spectroscopy to chemical problems. Topics discussed include ultraviolet, infrared, NMR, Raman, and mass spectroscopy.

527. ADVANCED ANALYTICAL CHEMISTRY

Spring term. Credit four hours. Prerequisite: Chemistry 286 or 388. Primarily for graduate students. Lectures, M W F 8. Mr. Geske. Offered in alternate years.

An intensive examination of contemporary electroanalytical chemistry, electrode kinetics, voltammetry including polarography, coulometry, and chronopotentiometry. Study of chromatographic separation including gas chromatography. Analytical significance of nonaqueous solutions.

565. PHYSICAL ORGANIC CHEMISTRY

Fall term. Credit four hours. Prerequisites: Chemistry 465–466 or consent of the instructor. Primarily for graduate students. Lectures, T Th S 12:20. Mr. Caldwell.

Mechanisms of organic reactions, with particular attention paid to the properties of reactive intermediates: carbonium ions, carbanions, free radicals, carbenes, and electronically excited molecules.

[566. PHYSICAL ORGANIC CHEMISTRY]

Spring term. Credit three hours. Prerequisite: Chemistry 565 or consent of the instructor. Primarily for graduate students. Lectures, T Th 12:20. Not offered in 1967–68.

Quantitative aspects of organic chemistry.

568. CHEMICAL PATHWAYS IN METABOLISM

Fall term. Credit four hours. Prerequisites: Chemistry 358 and 388, or their equivalents. Primarily for graduate students. Lectures, T Th S 8. Mr. Usher.

Bioenergetics, metabolic pathways, origin of life. This course forms the chemical basis for the graduate program in molecular biology.

[570. SELECTED TOPICS IN ORGANIC CHEMISTRY]

Fall term. Credit three hours. Prerequisites: 465–466 or consent of the instructor. Primarily for graduate students. Not offered in 1967–68.

572. ORGANIC MECHANISMS AND ENZYME CATALYSIS

Spring term. Credit four hours. Prerequisites: Chemistry 357–358 or equivalent, and a course in general biochemistry. Primarily for graduate students in chemistry and biochemistry. Lectures, M W F 11:15. Messrs. Hammes and Usher.

Model systems, functional groups, coenzymes; enzymes, kinetics, mechanism.

[574. CHEMISTRY OF NATURAL PRODUCTS]

Spring term. Credit three hours. Prerequisites: Chemistry 456 or 457, and 465–466. Primarily for graduate students. Lectures, T Th 12:20; discussion period, M 4:30. Not offered in 1967–68.

Particular attention will be devoted to methods of structure determination and synthesis as applied to selected terpenes, steroids, alkaloids, and antibiotics.

[577. CHEMISTRY OF NUCLEIC ACIDS]

Fall term. Credit four hours. Prerequisites: Chemistry 358 and 388, or their equivalents. Primarily for graduate students. Lectures, T Th S 8. Not offered in 1967–68.

578. THERMODYNAMICS

Spring term. Credit four hours. Prerequisite: 286 or 388. Primarily for graduate students. Lectures, T Th S 9:05, and a discussion period to be arranged. Mr. Hoard.

Development of the general equations of thermodynamics from the first and second laws. Applications to the study of physicochemical equilibria in gases, liquids, solids, and liquid solutions. Problems.

580. KINETICS OF CHEMICAL REACTIONS

Fall term. Credit four hours. Prerequisites: Chemistry 481 and 578, or consent of the instructor. Lectures, M W F 9:05. Mr. Hammes.

Principles and theories of chemical kinetics; special topics including fast reactions in liquids, enzymatic reactions, shock tubes and molecular beams.

582. SPECIAL TOPICS IN MOLECULAR BIOLOGY

Spring term. Credit four hours. Prerequisite: Chemistry 568 or consent of the instructor. Primarily for graduate students. Lectures, T Th S 11:15.

Detailed consideration is given to several special topics selected from recent

research activity in the field of molecular biology. Topics are varied from year to year.

586. PHYSICAL CHEMISTRY OF PROTEINS

Spring term. Credit four hours. Prerequisite: Chemistry 286 or 388. Primarily for graduate students. Lectures, M W F 8 and S 10:10; occasional lectures, W 7:30 P.M. Mr. Scheraga.

Chemical constitution, molecular weight, and structural basis of proteins; thermodynamic, hydrodynamic, optical, and electrical properties; protein and enzyme reactions; statistical mechanics of helix-coil transition in biopolymers; conformation of biopolymers.

589. X RAY CRYSTALLOGRAPHY

Fall term. Credit four hours. Prerequisite: Physics 322 or consent of the instructor. M W F 12:20. Offered in alternate years. Mr. Hoard.

Space groups, reciprocal lattices, three-dimensional diffraction, interpretation of x ray diffraction data, structure determination by Fourier synthesis.

593. QUANTUM MECHANICS I

Fall term. Credit four hours. Prerequisites: Chemistry 279 and Physics 303 (or coregistration in Physics 319) or their equivalents, and coregistration in Mathematics 421 (or equivalent), or consent of the instructor. Lectures, T Th 8:30–9:50. Mr. Fisher.

Schrödinger's equation, wave packets, uncertainty principle, WKB theory. Matrix mechanics, orbital and spin angular momentum, exclusion principle, perturbation theory, variational principle, Born-Oppenheimer approximation. At the level of Bohm, *Quantum Theory*.

594. QUANTUM MECHANICS II

Spring term. Credit four hours. Prerequisite: Chemistry 593 or its equivalent. Lectures, M W F 11:15. Mr. Freed.

Time-dependent phenomena in quantum mechanics and interaction with radiation. Group theory and applications. Topics in molecular quantum mechanics. At the level of Tinkham, *Group Theory and Quantum Mechanics*.

596. STATISTICAL MECHANICS

Spring trem. Credit four hours. Prerequisite: Chemistry 593 or equivalent is desirable but not required. Primarily for graduate students. Lectures, T Th 8:30–9:50. Mr. Fisher.

Ensembles and partition functions. Thermodynamic properties of ideal gases and crystals. Third law of thermodynamics, equilibrium constants, vapor pressures, imperfect gases, and virial coefficients. Distribution and correlation functions. Lattice statistics and phase transitions. Bose-Einstein and Fermi-Dirac ideal gases. Maxwell theory of viscosity and heat conduction. At the level of T. L. Hill, *Statistical Thermodynamics*.

598. SELECTED TOPICS IN PHYSICAL CHEMISTRY

Either term. Credit two or four hours.

Detailed consideration is given to special topics selected from the field of theoretical and experimental physical chemistry. Topics are varied from year to year.

600. GENERAL CHEMISTRY SEMINAR

Throughout the year. No credit. Th 4:40. A series of talks representative of all fields of current research interest in chemistry, given by advanced graduate students, research associates, faculty members, and distinguished visitors.

601–602. INTRODUCTORY GRADUATE SEMINAR IN ANALYTICAL, INORGANIC, AND PHYSICAL CHEMISTRY

Throughout the year. No credit. Hours to be arranged. Required of all first-year graduate students majoring in analytical, inorganic, physical, and theoretical chemistry, and molecular biology. Mr. Zuckerman.

Weekly seminars on contemporary topics prepared and presented by first-year graduate students. Attention given to details of selecting, preparing, and presenting a given topic. Group participation emphasized.

650–651. GRADUATE SEMINAR IN ORGANIC CHEMISTRY

Throughout the year. No credit. Open to qualified juniors, seniors, and graduate students. Required of all graduate students majoring in organic chemistry. M 8:15 P.M. Mr. Usher.

700. BAKER LECTURES

T Th 11:15. Fall term: V. Prelog, Technische Hochschule, Zurich. Spring term: G. Herzberg, National Research Council, Ottawa, Canada.

CIVIL ENGINEERING

Faculty: Vaughn C. Behn (Sanitary); Donald J. Belcher (Aerial Photographs); George H. Blessis (Construction Engineering and Administration); Wilfried Brutsaert (Hydrology); Nephi A. Christensen (Hydraulics); Leonard B. Dworsky (Water Resources, Pollution Control); Melvin I. Esrig (Soils); Louis M. Falkson (Applied Welfare Economics); Gordon P. Fisher (Structures and Environmental Systems); Richard H. Gallagher (Structures); Charles D. Gates (Sanitary); Peter Gergely (Structures); Walter H. Graf (Hydraulics); David J. Henkel (Soils); William L. Hewitt (Subgrades, Pavements); Alonzo W. Lawrence (Sanitary); Taylor D. Lewis (Transportation); Ta Liang (Aerial Photographs, Physical Environment); James A. Liggett (Hydraulics); Daniel P. Loucks (Water Resources Engineering); Walter R. Lynn (Environmental Systems); George B. Lyon (Surveying); William McGuire (Structures); Arthur J. McNair (Geodesy-Photogrammetry); Arthur H. Nilson (Structures); Charles S. ReVelle (Environmental Systems); Robert G. Sexsmith (Structures); Floyd O. Slate (Engineering Materials); Richard N. White (Structures); George Winter (Structures).

Field Representative: William McGuire, 218 Hollister Hall.

MAJOR AND MINOR SUBJECTS

Major Subjects

Aerial Photographic Studies (M.S. only)
Construction Engineering and Administration (M.S. only)
Environmental Systems Engineering
Geodetic and Photogrammetric Engineering
Hydraulics and Hydrology
Sanitary Engineering
Soil Mechanics and Foundation Engineering
Structural Engineering
Transportation Engineering
Water Resources Engineering (Ph.D. only)

Minor Subjects

Aerial Photographic Studies
Construction Engineering and Administration
Environmental Systems Engineering
Geodetic and Photogrammetric Engineering
Hydraulics and Hydrology
Sanitary Engineering
Soil Mechanics and Foundation Engineering
Structural Engineering
Structural Mechanics
Transportation Engineering
Water Resources Engineering

PROFESSIONAL DEGREE.

The School of Civil Engineering also offers the professional degree of Master of Engineering (Civil) which is intended primarily for those students who intend to enter engineering practice and who do not intend to obtain the doctorate. Work for this degree consists of courses which are designed to give the student a background in the elements of engineering design as well as a broad fundamental base. Those choosing the professional degree may concentrate their studies toward one or more of the sub-areas of civil engineering listed below or they may take a broad program without specific concentration.

ADMISSION REQUIREMENTS. To be admitted for graduate study in the Field of Civil Engineering, an applicant should hold a Bachelor's degree (or equivalent) in engineering, mathematics, or the sciences from a college of recognized standing.

LANGUAGE REQUIREMENTS. There are no language requirements for the M.S. degree in Civil Engineering or M.Engr. (Civil) degree. The Ph.D. requires a reading knowledge of one foreign language, usually French, German, or Russian.

EXAMINATIONS. Civil Engineering requires a final comprehensive examination for the M.S. degree. For the Ph.D. degree the student must take *(a)* a qualifying examination shortly after receiving his M.S. (which may be combined with the examination for the M.S.) or, if he comes to Cornell with an M.S., shortly after arrival; *(b)* a general examination on subject matter taken approximately at the time he completes his course work; and *(c)* a Final Examination in which the student is required to defend his dissertation.

FINANCIAL AID. Fellowships, traineeships, research assistantships, teaching fellowships, and laboratory assistantships are available to students seeking financial aid.

Additional information on specific programs is available by writing to the Field Representative, School of Civil Engineering. Study and research is usually carried on in one of the following areas:

Courses and Research

CIVIL ENGINEERING—GENERAL

2001. THESIS

The thesis gives the student an opportunity to work out a special problem or to make an engineering investigation, to record the results of his work, and to obtain academic credit for such work. Registration for thesis must be approved by the professor in charge at the beginning of the semester during which the work is to be done.

Individual courses may be arranged to suit the requirements of graduate students. They are intended to be pursued under the immediate direction of the professor in charge, the student usually being free from the restriction of the classroom and working either independently or in conjunction with others taking the same course.

2002. CIVIL ENGINEERING PRACTICE

Credit three hrs. On demand. Prerequisite: fourth year or graduate standing.

Analysis of large engineering works; planning and organizing engineering

and construction projects; professional practice; feasibility evaluations; financial justification of projects; social and political implications. The case method will be used extensively.

2010. CIVIL ENGINEERING DESIGN PROJECT, I

Credit two hrs. Fall. Normally required for students in the M.Eng. (Civil) Program. First term of a two-term sequence.

Design of a major civil engineering project embodying several aspects of civil engineering. Planning and part of preliminary design to be accomplished in the fall term. Remainder of preliminary design and final design in the spring term. Projects to be carried out by students working under the direction of a Faculty Project Coordinator.

2011. CIVIL ENGINEERING DESIGN PROJECT, II

Credit three hrs. Spring. Prerequisite: 2010. Normally required for students in the M.Eng. (Civil) Program.

Continuation of 2010.

ENVIRONMENTAL SYSTEMS ENGINEERING

Environmental Systems Engineering is a unique activity which has as its main thrust the application of systems analysis, operations research, and economics to the complex and massive technological problems of modern society. It is concerned with methods of allocation of resources in the public sector and with enhancement of the quality of information required for rational decision-making. Emphasis is given to transportation systems; air, water, and other natural systems; engineering (especially construction) project management; structural optimization and reliability, and automated design; solid waste disposal; and control of epidemic diseases. There is special interest in the problems of urbanization, including an integrated approach to the many technological and planning aspects of modern urban areas, and associated social and political factors.

Substantial effort is directed to research on large-scale problems such as interurban and urban transportation networks, transport terminal facilities and intermodal transfer efficiency, river basin studies, rationalization of complex construction projects, associated land use patterns and land values, and public investment. The economics, planning, and management of all forms of man-made and natural environment are stressed.

Through established relationships with the Departments of City and Regional Planning (College of Architecture, Art, and Planning), Operations Research, Geotechnical Engineering, Structural Engineering, Water Resources Engineering, and with many other parts of the University, students are encouraged to take advantage of a large variety of ancillary course offerings that support the general program of study.

Candidates for advanced degrees are considered with undergraduate or graduate work in any area of civil engineering, in operations research and industrial engineering, and in economics. Arrangements for students with other backgrounds and well-developed career objectives will be favorably considered.

201. MICROECONOMIC ANALYSIS

Credit three hrs. Fall. Lectures, M W 10:10 plus recitation section. Prerequisite: one year of college-level mathematics.

Topics include the theory of the firm, of production, of market structures, of consumer behavior, and of welfare economics.

202. MACROECONOMIC ANALYSIS

Credit three hrs. Spring. Lectures, M W (F) 10:10 plus recitation section. Prerequisite: 201.

Topics include the theory of international trade, national income determination, economic growth and stability, and monetary and fiscal policy.

2602. LAW FOR ENGINEERS

Credit three hrs. Fall. Three lectures.

Basic features of laws and practices relating to contracts, torts, agency, property, water rights, business organizations, sales, insurance, labor, governmental regulation of business, negotiable instruments, workmen's compensation, patents, ethical responsibilities of the engineer; term paper, comparative analysis of the legal principles which affected the court decisions in some actual cases.

2604. CONSTRUCTION ENGINEERING

Credit three hrs. Fall. Three recitations.

Introduction to methods, equipment, and engineering principles and procedures involved in construction activities; major emphasis is on heavy construction such as large earth-moving projects, tunnels, caisson foundations, etc.

2611. ECONOMICS OF ENVIRONMENTAL QUALITY MANAGEMENT

Credit four hrs. Fall. Prerequisite: 201 or equivalent.

A graduate seminar devoted to theoretical welfare economics and its application to the management of environmental quality.

2612. APPLIED WELFARE ECONOMICS

Credit one to four hrs. On demand. Prerequisite: permission of the instructor.

This seminar is an extension of 2611 with substantially greater emphasis on the application of welfare economics, statistics, and systems analysis to public investment decisions.

2617. ENVIRONMENTAL SYSTEMS ANALYSIS I

Credit three hrs. Three lectures. Fall. Prerequisite: permission of the instructor. Intended for graduate students but open to qualified undergraduates.

Structuring and solution of mathematical programming models with emphasis on linear programming and its extensions. Introduction to Lagrangian multipliers, dynamic programming, queuing theory and game theory. Application of systems analysis techniques to the solution of complex environmental engineering-economic problems.

2618. ENVIRONMENTAL SYSTEMS ANALYSIS II

Credit three hrs. Three lectures. Fall or spring. Prerequisite: 9320, 9522, or 9530, or permission of the instructor.

Advanced topics in the application of mathematical programming and probability theory to the solution of environmental engineering problems. Special emphasis on water resource systems planning and management. Students will be expected to identify and solve practical problems using systems analysis techniques.

2621. THEORY OF TRAFFIC FLOW.

Credit three hrs. On demand. Prerequisite: permission of the instructor.

2622. TRANSPORTATION SYSTEMS ANALYSIS

Credit three hrs. On demand. Prerequisite: 2617 or 9522 or equivalent.

Techniques of systems analysis are applied to physical planning, operating, and financing of transportation facilities. Wherever applicable, mathematical models of transportation processes are used to examine questions related to the development of optimal public policy decisions in the area of transportation. Attention is given to analysis of single and multimodal forms of transportation. Methods of mathematical programming, simulation, and stochastic processes are employed in studies of these systems.

2626. TRAFFIC ENGINEERING

Credit three hrs. Spring. Two recitations, one laboratory. Prerequisite: permission of the instructor.

City and highway traffic surveys and designs. Accidents, congestion, delay, speed, volume, density, parking, channelization, lighting, traffic control, and routing. Signs, signals, and markings. Urban traffic consideration in city planning. Driver reactions and habit pattern. Traffic engineering organization. Knowledge of digital computer programming procedures desirable but not mandatory.

2628. HIGHWAYS AND AIRPORTS

Credit three hrs. On demand. Prerequisite: 2601 or permission of the instructor. Route selection; design controls and criteria, including vehicle characteristics and highway capacity; sight distance, and horizontal and vertical control; right-of-way problems and access control; geometrics; at-grade intersection design; rotary and channelized intersection; grade separations and interchanges; regional systems of highways. Airport site selection, master plan, terminal facilities, heliports.

2631. CONSTRUCTION MANAGEMENT

Credit three hrs. Spring.

Planning and operation of construction projects by the civil engineer: coordinated organizations and control of men, materials, and machines; scheduling, estimating; purchasing; selection and training of employees, operation and maintenance of equipment; cost control; accident prevention; and other topics. Special reports required.

2691. ENVIRONMENTAL SYSTEMS DESIGN PROJECT

Credit variable. On demand. Prerequisite: permission of the instructor. May extend over two semesters.

Design or feasibility study of environmental systems, supervised and assisted by one or more faculty advisors. Individual or group participation. Final report required.

2692. ENVIRONMENTAL SYSTEMS ENGINEERING RESEARCH

Credit variable. On demand. Prerequisite: preparation must be suitable to the investigation to be undertaken; permission of the instructor is required.

For investigation in depth of particular environmental systems problems.

2693. ENVIRONMENTAL SYSTEMS ENGINEERING COLLOQUIUM

Credit one to two hrs. Fall or spring. Required of all graduate students with a major or minor in Environmental Systems Engineering. Open to advanced undergraduates by permission of the instructor.

Preparation, presentation, and informal discussion of topics concerned with environmental systems.

2694. SPECIAL TOPICS IN ENVIRONMENTAL SYSTEMS ENGINEERING

Credit variable. On demand.

Supervised study by individuals or small groups in one or more specialized topics not covered in regular courses.

In addition to the above listed courses, many courses in City and Regional Planning (College of Architecture, Art, and Planning), Business and Public Administration, Economics (College of Arts and Sciences), and especially Operations Research (see page 151) may be used to support studies in the general subject area of Environmental Systems Engineering.

GEOTECHNICAL ENGINEERING

Geotechnical Engineering is concerned with the study of the engineering properties and use of earth materials and with the measurement of the earth and its component parts. It includes soil and rock mechanics, foundation engineering, subgrades and pavements, studies of aerial photographs and other remote sensors, physical environment evaluation, surveying, geodesy and photogrammetry.

Graduate programs are designed to provide a sound theoretical and practical background in the various branches of the subject. The research interests of the faculty members cover a wide range of problems, and modern laboratory facilities are available to students for both teaching and research.

In soil mechanics and foundation engineering the current research is on strength and deformation properties of soils under a variety of loading conditions, and on the effects of passing electric currents through the soil. The methods of prediction and control of landslides are also being studied together with the soil mechanics problems related to vehicle mobility. In geodesy, surveying and photogrammetry, the research emphasis is on the development of photogrammetric methods for the measurement of the shape of large surfaces, such as that of the Arecibo Radio Astronomy Telescope, as well as of small surfaces such as of the human eyeball. The development of methodology for the measurement of earth movements is also being studied. Research is continuing in analytic aerotriangulation.

The work on aerial photographs and other remote sensing devices is concerned with physical environment evaluation; the use of satellites as platforms for remote sensing; the study of dam, railroad, and canal locations; and inventories of natural resources. A large library of photographs from all over the world is available for study and research.

Soil Mechanics and Foundation Engineering, Subgrades and Pavements

2406. FOUNDATION ENGINEERING

Credit three hrs. Spring. Three lectures. Prerequisite: 2401.

Principles of bearing capacity and deformation theory; stress distribution; shallow and deep foundations; prediction of settlement; design of footing, raft, caisson and pile foundations. Problems of construction, support of excavations; ground water lowering. Foundation investigations.

2410. ENGINEERING PROPERTIES OF SOILS

Credit three hrs. Fall. Three lectures. Prerequisite: 2401.

The natural environments in which soils are formed; the chemical and

physical nature of soils; soil classification; the principle of effective stress; shear strength and compressibility of saturated and partly saturated soils; sensitivity; effects of anisotropic consolidation; permeability; laboratory and field tests.

2412. GRADUATE SOIL MECHANICS LABORATORY

Credit three hrs. Spring. Prerequisite: 2410.

The laboratory measurement of soil properties: classification tests; direct shear tests; triaxial tests for the measurement of pore water pressure; strength parameters. Pore pressure dissipation tests. Relationship of laboratory tests to field behavior.

2414. EARTH PRESSURE AND SEEPAGE

Credit three hrs. Fall. Three lectures. Prerequisite: 2401.

The mechanics of the development of earth pressure in relation to soil properties and the imposed deformation conditions. The effects of seepage on the development of earth pressure. Design and stability of bulkheads and cofferdams. Pressures on shafts, tunnels and conduits. The steady and transient flow of fluids through compressible and incompressible porous media. Consolidation processes. Sand drains. Field determination of permeability. Flow nets and the modification of flow patterns by drains and relief wells.

2416. SLOPE STABILITY, EARTH AND ROCK-FILL DAMS

Credit three hrs. Spring. Three lectures. Prerequisite: 2410.

Principles of stability for earth and rock slopes; effects of pore water pressure; short and long term stability; problems of draw-down; analysis of landslides and dam stability; principles of earth and rock-fill dam design; internal pore water pressures and drainage; filters; relief wells; foundation problems; grouting; cut-offs; control and instrumentation.

2418. CASE STUDIES IN SOIL MECHANICS AND FOUNDATION ENGINEERING

Credit three hrs. Spring.

The study of real engineering problems of various types; the importance of the geological environment in recognizing the nature of field problems; the application of mechanics and soil properties to obtain engineering solutions. The preparation of engineering reports.

AERIAL PHOTOGRAPHIC AND PHYSICAL ENVIRONMENT STUDIES

2421. PHYSICAL ENVIRONMENT EVALUATION

Credit three hrs. Fall. Two lectures, one laboratory. Intended for graduate students or upperclassmen in engineering and planning. Permission of the instructor is required.

A study of physical environment factors affecting engineering and planning decisions and the evaluation methods of these factors. Physical factors include the climate, soil and rock conditions, and water sources in different parts of the world. Evaluation methods include air and ground reconnaissance, interpretation of meterological, topographic, geological, and soil maps, aerial photography, engineering data, and sub-surface exploration records.

2422. ADVANCED PHYSICAL ENVIRONMENT EVALUATION

Credit three hrs. Spring. Two lectures, one laboratory. Intended for graduate students or upperclassmen in engineering or planning. Prerequisite: 2421 or 2423 or permission of the instructor.

A study of physical environment by use of airphotos and other remote-sensing methods. Conventional photography, sequential photography, multiple spectral photography, space photography, infrared thermal and radar images are included in the study. Evaluation of environment is directed to the planning of engineering and development projects in general, and some emphasis on those related to special climatic regions such as tropical humid as well as arid regions.

2423. ANALYSES AND INTERPRETATION OF AERIAL PHOTOGRAPHS

Credit three hrs. Fall-spring. Two lectures, one laboratory. Preregistration required. (The student is expected to pay the cost of field trips and aerial photographs for use in a term project, amounting to approximately $15.)

A study of the soil and rock areas of the United States and the patterns present in aerial photographs. Fundamental elements of soil patterns are analyzed to permit determination of soil texture, type of bedrock, and drainage properties. Field training in selected test areas.

2424. ADVANCED INTERPRETATION OF AERIAL PHOTOGRAPHS

Credit three hrs. Fall-spring. Preregistration required.

Course includes lectures and team projects in laboratory and field. Facilities include material for city-regional planning, soil mapping, conservation, ground and surface water and civil engineering projects.

2431. SUBGRADES AND PAVEMENTS FOR HIGHWAY AND AIRPORTS

Credit three hrs. Spring. Two lectures, one laboratory. Prerequisite: 2601 or permission of the instructor.

Part I: Subgrade evaluation; compaction; drainage and frost action; stabilization. Part II: Aggregates; bituminous materials; evaluation of flexible pavement components; design and construction of flexible pavement structure. Part III: Design and construction of rigid pavements.

2432. LOW-COST ROADS

Credit three hrs. Primarily for foreign students. Offered upon sufficient demand, usually in fall term. Prerequisite: consent of the instructor. Principally directed study with a two-and-a-half-hour class session per week to be arranged.

Rural road systems as instruments of economic development. Study of economic considerations in road system improvement; road improvement planning and programming; road location and geometric design; engineering soil characteristics; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces.

GEODETIC AND PHOTOGRAMMETRIC ENGINEERING

2452. ELEMENTS OF SURVEYING

Credit two hrs. Fall-spring. One lecture, one laboratory.

Fundamentals of engineering measurements. Study of observations and errors. Principles of recording data. Use of steel tape, level, and transit. Optical tooling. Photogrammetry. Problems of particular interest to students in fields other than civil engineering.

2461. ELEMENTARY GEODESY

Credit three hrs. Fall. Three lectures.

Principal problems of geodesy. Coordinate systems, reference datum. Geometric problems on earth ellipsoid. Geometric astronomy. Application of Bjerhammar singular matrix calculus; singular matrices to geodesy.

2462. GEOPHYSICAL GEODESY

Credit three hrs. Spring. Three lectures.

Basic potential theory, Laplace and Poisson equations; gravity and potential field in, on, and outside the spheroid; figure of the earth, application of Stokes formula for determining undulations of the geoid and deflection of the vertical; applications of spherical harmonics.

2463. GEODETIC CONTROL SURVEYS

Credit three hrs. Two lectures, one laboratory. Prerequisite: 2451 or 2461.

Principles of establishing a geodetic sea-level datum; isostasy, the geoid and ellipsoid; altimetry, trigonometric, spirit, and electronic leveling; orthometric and dynamic heights; electronic distance measurement; triangulation and trilateration; design of control networks and systems; astronomic and gravimetric observations, and satellite triangulation.

2464. GEODETIC ASTRONOMY

Credit two hrs. Two lectures. Prerequisite: 2451 or equivalent work in field astronomy.

Study of the precise determination of latitude, longitude, and azimuth from astronomical observations. Night observation periods.

2465. ADVANCED ENGINEERING MEASUREMENTS

Credit three hrs. Fall. Prerequisites: laboratory work involving physical measurements, Math 293 or equivalent.

Measurement systems; analysis of errors and of error propagation; application of the principles of probability to the results of measurements for the purpose of determining the best estimates of measured and deduced quantities; and the best estimate of uncertainty in these quantities; adjustment of conditioned measurements by the method of least squares and other methods; and curve fitting.

2466. MAP PROJECTIONS AND CARTOGRAPHY

Credit three hrs. Three lectures. On demand.

Theory of map projections including conformal, equal-area, azimuthal equidistant, et al. projections; coordinate transformations; plane coordinate systems for surveying. Design of map projections. Cartographic principles, systems, and related economic factors.

2471. ELEMENTS OF PHOTOGRAMMETRY

Credit three hrs. Fall. Lecture, laboratory.

Principles and practice of terrestrial and aerial photogrammetric mapping, including planning flights, control surveys, uncontrolled mosaics, radialline control, simple stereoplotting instruments, parallax distortions, graphical tilt determination, trimetrogen charting, and economics. A Balplex projection stereoplotter with three projectors is available for use.

2472. ADVANCED PHOTOGRAMMETRY

Credit three hrs. Spring. Two lectures, one laboratory. Prerequisite: 2471.

An advanced study of photogrammetric principles including: controlled mosaics; rectification; graphical and instrumental aerotriangulation. Principles

of photogrammetric plotters and systems and the economic relation of these to density of ground control, office methods, and personnel. Balplex projection plotter is used extensively.

2473. ANALYTICAL AEROTRIANGULATION

Credit three hrs. Three lectures. Prerequisite: 2471.

Analysis, theories, and computation of stereostrip triangulation by direction cosines, vector, and matrix methods. Coplanarity and colinearity equations for relative orientation and absolute orientation. Stereogram assemblage and coordinate transformation of strip and block coordinates. Cantilever extension and general bridging solutions. Propagation of errors.

2481. CADASTRAL SURVEYING

On demand. Credit three hrs. Three lectures.

Study of legal principles and surveying operations associated with acquisition of evidence for the delineation of boundaries of real estate. Topics covered include: metes and bounds, subdivision, and other methods of description of real property; land courts; riparian rights; mineral rights; resurveys; and authority and responsibilities of the Cadeastral surveyor.

2482. ENGINEERING SURVEYS

Credit three hrs. Spring. One lecture, two laboratories. Prerequisite: 2451 or equivalent.

Circular curves, transition curves, earthwork measurement and calculation, topographic surveys, construction surveys, and project planning from maps.

2491. GENERAL DESIGN PROJECT IN GEOTECHNICAL ENGINEERING

Credit one to six hrs. On demand.

Design problems frequently associated with the Master of Engineering Program.

2492. RESEARCH IN GEOTECHNICAL ENGINEERING

Credit one to six hrs. On demand. For students who wish to study one particular area of geotechnical engineering in depth.

The work may take the form of a laboratory investigation, field study, theoretical analyses or the development of design procedures.

2493. SEMINAR IN GEOTECHNICAL ENGINEERING

Credit one to two hrs. On demand.

Presentation and discussion of technical papers and current research in the general field of geotechnical engineering or one of its specialized fields.

2494. SPECIAL TOPICS IN GEOTECHNICAL ENGINEERING

Credit one to six hrs. On demand.

Supervised study in small groups in one or more special topics not covered in the regular courses. Special topics may be of a theoretical or applied nature.

2495. FIELD PRACTICE IN GEOTECHNICAL ENGINEERING

Credit three hrs. Extends throughout the academic year with field studies conducted as two-day trips allocated to appropriate weekends in each term. The student is expected to pay transportation and related costs, amounting to approximately a total of $85. Prerequisite: 2401 or permission of the instructor.

Designed to provide experience with field conditions in important project environments within reach of the campus, including construction scenes in

New York and central Pennsylvania. Preparation for and reports on various sites is a requirement.

The program includes field testing and sampling; resistivity and seismic probing of soils and bedrock; soil moisture and density measurements using nuclear equipment. Engineering construction practices and site evaluation related to landslides, bedrock, drainage, and unstable soils. The influence of rock types, ground water, and soil materials on existing structures; appropriate design procedures applied to sophisticated structures at difficult sites.

STRUCTURAL ENGINEERING

Structural engineering embraces not only the more conventional aspects of civil engineering design but also other structural work, such as aeronautical and space structures, nuclear engineering structures, tanks, bins, pressure vessels, antenna towers, and the like. Emphasis is placed on the common fundamental background, theoretical and experimental, of all structural engineering. Structural and materials behavior being inseparably related, instruction and research in the field of structural materials is regarded as part of the area of structural engineering.

Complete facilities for experimental structural research of all kinds are available including a structural testing hall fifty feet by eighty feet in plan, and forty-five feet high for full-scale three-dimensional static and fatigue testing of structures; static- and fatigue-testing machines of a variety of capacities; appropriate measuring equipment; a versatile and fully equipped structural models laboratory; and a large laboratory for concrete and other cementitious materials.

The department has a large number of externally and internally sponsored research projects upon which students can base theses and receive research assistantships. The externally sponsored projects include: shell structure of light gage steel, microcracking of concrete and its influence on structural behavior and fracture, shear strength of light gage steel diaphragms, behavior of beams and columns continuously braced by diaphragms, performance of stainless steel structural members, torsional-flexural buckling of eccentrically loaded columns, fundamental concepts of cracking phenomena in reinforced concrete structures, effects of cold forming on performance of light gage steel members, reinforced concrete models, and thermal stresses in nuclear reactors.

A separate brochure on *Structural Engineering at Cornell University* is available on request from the School of Civil Engineering, Hollister Hall.

2710. STRENGTH OF STRUCTURES

Credit three hrs. Fall. Three recitations. Prerequisite: 2704; can be taken concurrently.

Analysis of two- and three-dimensional stress and strain. Theories of failure of ductile and brittle materials. Microstructure of materials. Structural materials under load, strain hardening, Bauschinger effect, residual stresses, hysteresis, stress concentration, brittle fracture, creep, alternating stress. Design for fatigue. Stresses beyond the elastic limit. Inelastic behavior of steel and reinforced concrete structures. Critical discussion of recent research and current design specifications.

2711. BUCKLING: ELASTIC AND INELASTIC

Credit three hrs. Spring. Prerequisite: 2710.

Analysis of elastic and plastic stability. Determination of buckling loads and postbuckling behavior of columns. Solid and open web columns with

variable cross-section. Beam columns. Frame buckling. Torsional-flexural buckling. Lateral strength of unbraced beams. Buckling loads and post-buckling strength of plates, shear webs, and cylindrical shells. Critical discussion of current design specification.

2712. ADVANCED STRUCTURAL ANALYSIS I

Credit three hrs. Fall. Three lectures per week. Prerequisites: 2703 or equivalent; concurrent registration in Computer Science 311.

First half: stability, determinacy, redundancy of structures, approximate methods of analysis, brief review of classical methods for deflection calculation and indeterminate analysis, and extension to complex systems. Second half: introduction to matrix methods of analysis, force and displacement methods.

2713. ADVANCED STRUCTURAL ANALYSIS II

Credit three hrs. Spring. Three lectures per week. Prerequisite: 2712.

First half: force, displacement, and mixed mode methods of matrix analysis, self-strained structures, generalized forces and displacements, large-order systems, finite element analysis, including plane stress and plane strain, frameworks, and plate bending, principles of optimization. Second half: arches, including secondary stress analysis, suspension systems, plastic analysis, torsion, curved beams, grids.

2714. STRUCTURAL MODEL ANALYSIS AND EXPERIMENTAL METHODS

Credit three hrs. Spring. Two lectures, one two-hour period. Prerequisite: indeterminate analysis.

Dimensional analysis and principles of similitude. Indirect model analysis of beams, frames, and trusses. Direct model analysis including loading and instrumentation techniques. Strain measurement and interpretation. Confidence levels of model results. Laboratory projects in elastic behavior and ultimate strength of model structures.

2715. NUMERICAL METHODS IN STRUCTURAL ENGINEERING

Credit three hrs. Fall. Prerequisites: differential equations and consent of the instructor; concurrent registration in FORTRAN instruction.

Newmark's method and other numerical integration techniques. Solution of linear systems. Finite difference techniques for stress, stability, and other boundary value problems. Eigenvalue determination. Applications of digital computers in structural engineering analysis and design, including introduction to optimization techniques. Independent projects involving extensive use of digital computer.

2716. CONCRETE STRUCTURES I

Credit three hrs. Fall. Three lectures per week. Prerequisite: 2703 or equivalent.

Analysis, design, and behavior of prestressed concrete structures; beams, slabs, composite construction, continuous beams and frames, tension and compression members; deflection analysis, end zone stresses, detailing, losses, efficiency. Design of concrete shells: shells of revolution, hyperbolic paraboloids.

2717. CONCRETE STRUCTURES II

Credit three hrs. Spring. Three lectures per week. Prerequisite: 2703 or equivalent.

Analysis, design and behavior of reinforced concrete structures; safety considerations, deflection analysis, crack control; beams, columns, slabs, continuous frames, flat plates, flat slabs, composite construction; limit analysis and yield line theory; design of concrete shells: folded plates and cylindrical shells.

2718, 2719. BEHAVIOR AND DESIGN OF METAL STRUCTURES

Credit three hrs. a term. Fall-spring. Prerequisite: 2703 or equivalent.

Contemporary methods for analyzing and designing metal structures. Behavior of structural elements and frames. Selected design applications from the fields of steel plate structures, bridges, suspension systems, light weight structures.

2720. SHELL THEORY AND DESIGN

Credit three hrs. Fall. Prerequisites: Math 294 or equivalent and consent of the instructor.

Differential geometry of surfaces. Bending and membrane theory of shells. Analysis and design of cylindrical shells, domes, paraboloids. Application of reinforced concrete roofs and pressure vessels. Stability of certain types of shells.

2721. SPECIAL TOPICS IN MATRIX ANALYSIS

Credit two hrs. Spring. Two lectures per week. Prerequisite: a prior exposure to matrix methods of structural analysis; 2713 may be taken concurrently.

Analysis of tall buildings. Methods of tridiagonalization, transfer matrices. Iterative and direct solutions. Finite element analysis. Nonlinear problems. Eigenvalue problems; buckling and dynamic analysis.

2722. DYNAMICS OF STRUCTURES

Credit three hrs. Spring. Prerequisites: Math 294 or equivalent and consent of the instructor.

Equations of motion and vibration of simple systems. Numerical, energy and matrix methods of analysis of multiple degree systems. Analysis and design of structures for ground disturbances, including inelastic effects.

2730. AEROSPACE STRUCTURES ANALYSIS I

Credit three hrs. Fall. Two lectures per week plus assigned reading. For Aerospace and Civil Engineering graduate students.

First half: definition of aerospace structures, design environments, specifications, constructional concepts, material properties, modes of failure, directed reading in structural analysis. Second half: second half of 2712.

2731. AEROSPACE STRUCTURES ANALYSIS II

Credit three hrs. Spring. Three lectures per week. Prerequisite: 2730.

First half: first half of 2713. Second half: idealization techniques; application of finite element methods to aerospace structures. Elasticity procedures. Elastic instability: prismatic members and plates.

2752. ADVANCED PLAIN CONCRETE

Credit two hrs. Spring. Two lectures. Prerequisite: 2751 or the equivalent.

Topics in the field of concrete, such as history of cementing materials, air-entrainment, light weight aggregates, petrography, durability, chemical reactions, and properties of aggregates. Relationships between internal structure, physical properties, chemical properties, and the mechanical properties of interest to the design and construction engineer.

2753. STRUCTURE AND PROPERTIES OF MATTER

Credit three hrs. Fall. Two lectures plus conference. Open to graduate students in engineering or the physical sciences or by consent of the instructor.

Internal structure of materials ranging from the amorphous to the crystalline state. Correlation of the internal structures of materials with their physical and mechanical properties, primarily on a qualitative basis. Applications to various engineering materials.

2757. CIVIL ENGINEERING MATERIALS PROJECT

On demand. Credit one to six hrs.

Individual projects involving civil engineering materials.

2758. CIVIL ENGINEERING MATERIALS RESEARCH

On demand. Hours and credit variable.

Individual assignments, investigations and/or experiments with civil engineering materials.

2791. DESIGN PROJECT IN STRUCTURAL ENGINEERING

(Meets project requirement for M. E. degree.) Credit one hr. fall and three hrs. spring; both terms required.

Comprehensive design projects by design teams. Formulation of alternate design proposals, including economics and planning, for a given situation, and complete design of the best alternate. Determination of construction costs and preparation of sketches and drawings. Presentation of designs by oral and written reports.

2792. RESEARCH IN STRUCTURAL ENGINEERING

On demand. Hours and credit variable. Students wishing to pursue one particular branch of structural engineering further than can be done in any of the regular courses may elect work in this field. The prerequisite courses depend upon the nature of the work desired.

The work may be in the nature of an investigation of existing types of construction, theoretical work with a view of simplifying present methods of design or proposing new methods, or experimental investigation of suitable problems.

2793. STRUCTURAL ENGINEERING SEMINAR

Credit one to three hrs. Spring. Open to qualified seniors and graduate students. Preparation and presentation of topics of current interest in the field of structures for informal discussion.

2794. SPECIAL TOPICS IN STRUCTURAL ENGINEERING

On demand. Hours and credit variable.

Individually supervised study in one or more of the specialized topics of civil engineering such as tanks and bins, suspension bridges, towers or movable bridges, which are not covered in the regular courses. Independent design or research projects may also be selected.

HYDRAULICS AND HYDROLOGY

Two modern laboratories make possible a wide range of instructional and research experimentation. In the Hollister Hall applied fluid mechanics laboratory, well-instrumented models support experimental studies in all

phases of fluid flow. At the Applied Hydraulics Laboratory near Beebe Lake, flows up to fifty cubic feet per second and natural heads up to eighty feet are available for both research and testing.

Current staff research in hydraulics and hydrology include studies in Secondary Currents in Noncircular Conduits; Settling Velocities in a Turbulent Environment; Mathematical Models of Hydrologic Systems; Unsteady River Flows; Circulation in a Shallow Homogeneous Lake; Random Structure of Drought Flows; Time Series Analysis of Lake Evaporation; The Physics of Pan Evaporation; Drainage from Large Unconfined Aquifers; Permeability Models for Porous Materials; Recovery of Infiltration Capacity in Soils and Hysteresis; Sediment Transport in Pipes; Roughness Investigations in Rivers; Influence of Ice on the River Stage.

2303. HYDROLOGY

Credit two hrs. Fall. Two lecture-recitations. Prerequisite: 2301.

Introduction to hydrology including topics on precipitation, evapotranspiration, ground water, surface water, sedimentation.

2312. EXPERIMENTAL AND NUMERICAL METHODS IN FLUID MECHANICS

Credit two hrs. Fall-spring. Prerequisite: 2302 or permission of the instructor. Primarily a laboratory course for undergraduates and graduates; may be repeated for credit on permission of the instructor.

Emphasis is on planning and conducting laboratory and field experiments and on numerical computation. Each section is limited to four students.

2315. ADVANCED FLUID MECHANICS I

Credit three hrs. Fall. Three recitations. Prerequisite: 2301.

Introduction to vector and tensor notation. The equations of conservation of mass, momentum, and energy from a rigorous point of view. Similitude and modeling potential flow including circulation, vorticity, conformal mapping, and hodograph methods.

2316. ADVANCED FLUID MECHANICS II

Credit three hrs. Spring. Three recitations. Prerequisite: 2315.

Exact solutions to the Navier-Stokes equations, the laminar and turbulent boundary layers, turbulence, introduction to non-Newtonian flow, and other topics.

2317. FREE SURFACE FLOW

Credit three hrs. Spring. Three recitations. Prerequisite: 2315 or permission of the instructor.

The formulation of the free surface equations and boundary conditions. Shallow water theory and the theory of characteristics. Unsteady and two-dimensional flow in open channels. Theory of small amplitude waves.

2320. SURFACE-WATER HYDROLOGY

Credit three hrs. Fall. Prerequisite: 2301.

Physical and statistical analysis relating to hydrologic processes. Hydrometerology and evaporation. Surface runoff, base flow and storage routing in linear and nonlinear systems. Unit hydrograph theory.

2321. FLOW IN POROUS MEDIA

Credit three hrs. Spring. Prerequisite: 2301 (also recommended, 2315).

Fluid mechanics of flow through porous solids. The general equations of single phase and multiphase flow and the methods of solving the differential form of these equations. Hydraulics of wells, of infiltration and of ground water recharge, and of other steady state and transient seepage problems in fully and partially saturated materials.

2331. RIVER AND COASTAL HYDRAULICS

Credit three hrs. Spring. Prerequisite: 2302 or permission of the instructor.

First part deals with the hydraulics of fixed bed channels including the specific energy concept, secondary currents, rapid flow problems, artificial obstructions in channels, and the general problem of frictional resistance. In the second part, attention is paid to coastal and oceanographical engineering problems including the theory of waves, breaking of waves, wave refraction and wave diffraction.

2332. SEDIMENT TRANSPORT

Credit three hrs. Fall. Prerequisite: 2302 or permission of the instructor.

Hydraulics of channels with a movable bed including particle mechanics, critical tractive force theory, the DuBoys Problem, the Swiss formulas, Einstein's Bedload theory, the suspension and saltation theory, calculation of total sediment loads. Interesting problems in fluvial hydraulics will be included.

2333. FLUVIAL PROCESSES

Spring. Credit two hrs. Prerequisite: consent of the instructors. Seminar, hours to be arranged, field trips. Course offered jointly with Department of Geological Sciences. On demand.

The common problems of fluvial processes, hydraulics, and sediment transport are studied along with the appropriate analytical methods and experimental techniques.

2391. PROJECT

Offered on demand. Hours and credit variable.

The student may elect a design problem or undertake the design and construction of special equipment in the fields of fluid mechanics, hydraulic engineering or hydrology.

2392. RESEARCH IN HYDRAULICS

Offered on demand. Hours and credit variable.

The student may select an area of investigation in fluid mechanics, hydraulic engineering, or hydrology. The work may be either of an experimental or theoretical nature. Results should be submitted to the instructor in charge in the form of a research report.

2393. HYDRAULICS SEMINAR

Credit one hr. Fall-spring. Open to undergraduates and graduates and required of graduate students majoring in hydraulics or hydraulic engineering.

Topics of current interest in fluid mechanics, hydraulic engineering, and hydrology.

2394. SPECIAL TOPICS IN HYDRAULICS

Offered on demand. Hours and credit variable.

Special topics in fluid mechanics, hydraulic engineering, or hydrology.

SANITARY ENGINEERING AND WATER RESOURCES ENGINEERING

Graduate study and research in sanitary engineering is concerned with the development of fundamental knowledge of pertinent physical, chemical and biological phenomena and principles. This knowledge, along with skills in applied mathematics, statistics and probability is then used in the analysis and design of processes, structures and systems for water quality control, water quantity control and waste management. Advanced study in water resources engineering offers an opportunity to develop and combine competence in water quality technology, hydraulics, hydrology, economic theory, and operations research; and to apply this knowledge to the solution of engineering problems in water resources planning and management. The sanitary engineering facilities contain some 6,300 square feet of laboratory space and controlled temperature rooms and include separate specially equipped laboratories for water bacteriology and biology, water chemistry, bench and pilot-level unit process studies for radiological measurements.

Students and staff are currently collaborating in such diverse research areas as the oxidation of organic wastes in receiving waters, formulation of biological oxidation kinetics, mathematical decision models for the operation of water resource systems, design of water quality monitoring systems, and water pollution control policies.

2502. WATER AND WASTE-WATER TREATMENT PROCESSES

Credit three hrs. Two lectures, one laboratory. Spring. Prerequisite: 2301 and 2302.

Study of the microbiological, chemical, and physical phenomena underlying the treatment of water and of municipal and industrial waste-water. Application of these principles to the analysis and design of unit treatment processes. Laboratory studies of water quality and of unit treatment processes.

2510. CHEMISTRY OF WATER AND WASTE-WATER

Credit three hrs. Two lecture-recitations, one laboratory. Fall. Prerequisite: one year of college chemistry.

Principles of chemistry applicable to the understanding, design and control of water and waste-water treatment processes and to reactions in receiving waters. Analytical methods applicable to the measurement and control of air and water quality.

2512. MICROBIOLOGY OF WATER AND WASTE-WATER

Credit three hrs. Two lectures, one laboratory. Spring.

Introduction to the characteristics of microorganisms, their interaction with the environment; and their effect on water quality. Their role in the oxidation of organic substances in waste-water treatment and in receiving waters. Bacteriological, biological and limnological parameters of water quality and their measurement.

2513. TREATMENT PROCESSES

Credit three hrs. Three lectures. Fall. Prerequisite: 2502 or equivalent.

Analysis and design of processes for the removal of impurities from water and from municipal and industrial waste-water. Theoretical and applied aspects of treatment process design, including reaction kinetics, transfer phenomena, and the mechanics of fine particles.

2514. ASSIMILATION OF WASTES IN WATER

Credit three hrs. Three lectures. Spring. Prerequisite: appropriate undergraduate course.

Capacity of water resources to assimiliate gaseous, liquid and particulate wastes. Phenomena pertinent to the dispersion and stabilization of wastes in water. Analog and digital computer methods. Emphasis on the advanced literature.

2515. WATER RESOURCES PROBLEMS AND POLICIES

Credit three hrs. Lecture-discussion. Fall. Prerequisite: permission of the instructor. Intended primarily for graduate engineering and nonengineering students but open to qualified undergraduates.

A comprehensive approach to water resources planning and development. Historical and contemporary perspectives of water resources problems, organization and policies.

2516. PHYSICAL BASIS OF WATER RESOURCE PLANNING

Credit two hrs. Lecture-discussion. Fall. Intended primarily for nonengineering graduate students taking water resources as a minor subject.

An introduction to hydrologic systems with topics in climate; surface and ground water flow; flood abatement and water quality control. Offers technical background material useful in subsequent courses in the water resources area.

2520. ENVIRONMENTAL HEALTH ENGINEERING

Credit three hrs. Three lectures, reports. Spring. Prerequisite: 2501, or equivalent, or permission of the instructor.

Concepts of environmental health, principles of epidemiology and of toxicology. Introduction to radiological health. Consideration of problems in environmental control with emphasis on waste management, water quality control, air quality control, and solid waste disposal.

2532. ENVIRONMENTAL SANITATION

Open to other than civil engineering students. Credit three hrs. Fall. Lecture-discussion, reports, and field trips.

Environmental health concepts and methods, and their application to environmental planning and control at the subdivision, municipal, and metropolitan levels. Introduction to: water resource planning and development; water quality control; water supply; municipal, industrial, and private waste-water disposal; air quality control; solid waste disposal and radiological health.

2535. THE LEGAL BASIS OF WATER RESOURCES PLANNING

Credit three hrs. Spring or fall. Prerequisite: permission of the instructor.

The course is designed specifically for other than law students who are interested in the legal aspects of water resources planning, development and management.

2545. WATER RESOURCES PLANNING SEMINAR

Credit three hrs. Spring. Prerequisite: 2515 or permission of the instructor.

The concepts, processes, and techniques of regional, multi-purpose river basin planning and development. The case study method, including the preparation of an integrated, comprehensive report for the study area, is followed.

2547. SEMINAR IN WATER RESOURCES SYSTEMS ANALYSIS

Credit four hrs. Spring or fall. Prerequisite: permission of the instructor which will be based on the student's ability to contribute substantially to the seminar.

An interdisciplinary approach to the solution of a complex problem in water resources engineering involving the application of systems analysis, statistics, economic theory, hydrology and hydraulic and sanitary engineering. Each student will study and discuss a particular aspect of the problem. The results of the individual studies should contribute to the solution of the overall problem. Taught by engineering and economics faculty.

2591. DESIGN PROJECT IN WATER RESOURCES ENGINEERING OR IN SANITARY ENGINEERING

On demand. Credit variable. Prerequisite: 2501 or 2502 or equivalent.

The student will elect or be assigned problems in the design of water and waste-water treatment processes or plants; waste-water disposal systems; water quality control systems; water resource development or management systems; or of laboratory apparatus of special interest.

2592. SANITARY ENGINEERING RESEARCH

On demand. Credit variable. Prerequisites will depend upon the particular investigation to be undertaken.

For the student who wishes to study a special topic or problem in greater depth than is possible in formal courses.

2593. SANITARY ENGINEERING COLLOQUIUM

Credit one to two hrs. Fall–spring. Required of all graduate student taking a major or minor in sanitary engineering; open to undergraduates by permission of the instructor.

Preparation, presentation, and discussion of topics and problems of current interest in sanitary engineering and water resources engineering.

COMPUTER SCIENCE

Faculty: H. D. Block, Kenneth M. Brown, Richard W. Conway, Patrick C. Fischer, Juris Hartmanis, John E. Hopcroft, William L. Maxwell, Charles W. Merriam, Anil Nerode, Lawrence E. Payne, Christopher Pottle, Gerard Salton, Sidney Saltzman, Shayle R. Searle, Robert J. Walker, Peter Wegner.

Field Representative: Robert J. Walker, Upson Hall.

MAJOR AND MINOR SUBJECTS

Computer Science	Numerical Analysis
Information Processing	Theory of Computation

ADMISSION REQUIREMENTS: As prerequisite for admission in this Field, a student is expected to have had significant experience in programming a digital computer, and depending upon the particular subject major chosen, appropriate background in mathematics, engineering, linguistics, etc., to permit the immediate enrollment in graduate level courses. A student is also expected to have had at least an introductory course in computer science although this deficiency can be remedied after admission.

FOREIGN LANGUAGE REQUIREMENTS. A candidate for the degree of Ph.D. must demonstrate reading ability in two approved languages besides English. Approved languages are French, German, Russian, and any language in which there exists a substantial body of literature in the area of the student's doctoral thesis. There is no Field requirement of a foreign language for the M.S. degree.

Any Special Committee may, at its discretion, require knowledge of foreign language beyond the above requirements.

OTHER FIELD REQUIREMENTS. All candidates for the Ph.D. are required to have at least one minor in a Field other than Computer Science. The most frequent choices would be in the Fields of Mathematics, Applied Mathematics, Statistics, Operations Research, Electrical Engineering, Ecology and Evolutionary Biology, Psychology, or Linguistics, but others would be possible.

A comprehensive oral examination is required before the granting of the M.S. degree or admission to Ph.D. candidacy. This examination is normally taken after the completion of formal course work and the satisfaction of any foreign language requirements.

One semester of part time teaching experience is required for the Ph.D. degree.

General Comments

The Field of Computer Science at Cornell includes not only the fundamental theoretical material in automata, computability, and language structure but also such subjects as numerical analysis and information processing, which underlie broad areas of computer application. A graduate student should consider a major in computer science if he is primarily interested in the general aspects of computational processes, both theoretical and pratical, e.g., theory of algorithms, methods by which algorithms are implemented on a computer, and information structures. If he is primarily interested in the result of a computer process and its relation to a particular area of application, then he should major in another Field and consider a minor in Computer Science.

Research and Study Opportunities

Opportunities exist for research and study in the following areas of Computer Science: numerical analysis (Brown, Payne, Walker), programming languages and systems (Conway, Maxwell, Saltzman, Wegner), automata and computability theory (Fischer, Hartmanis, Hopcroft, Nerode), information organization and retrieval (Salton), systems and control theory (Merriam, Pottle), adaptive systems (Block).

Facilities

Students and staff offices in computer science are located in Upson Hall. The principal computing facility at Cornell is a multi-processor complex of IBM 360 systems. The central machine is a 360/65 with a 360/40 serving as an attached support processor. This is located in Langmuir Laboratory at the Cornell Research Park on the periphery of the campus and is directly

linked to satellite computers at three different locations on campus. The Engineering College is served through one of these satellite stations in Upson Hall as well as by a number of teletypewriter terminals in different locations. An IBM 1800 computer is also linked to the central computer to provide an analog-digital interface and graphical display equipment. In addition to this new remote-access system, Cornell operates an IBM 1401 and a Control Data 1604 with a satellite 160A.

A booklet describing in more detail the graduate work at Cornell in Computer Science and closely related subjects can be obtained by writing to the Field Representative, Upson Hall.

Courses

385. AUTOMATA

Spring term. Credit three hours. Prerequisite: Mathematics 294 or 222 or equivalent. M W F 10:10. Mr. Hopcroft.

The capabilities, limitations and structures of finite automata, Turing machines and other abstract computing devices will be studied. Applications to questions of undecidability and artificial intelligence.

401. COMPUTER ORGANIZATION AND PROGRAMMING

Either term. Credit four hours. Prerequisite: Mathematics 221 or 293 or equivalent. Not open to students with credit for Engineering 9481 or 9381. T Th 11:15, W 2:30–4:25. Mr. Pottle.

Characteristics and structure of digital computers. Programming in assembly and higher-order languages. Representation of data, index registers and indirect addressing, program organization, macro operations, recursive procedures, interpretive routines, auxiliary storage and input-output, operating systems.

411. INFORMATION AND COMPUTER STRUCTURES

Fall term. Credit four hours. Prerequisite: 401 or equivalent. T Th 9:05, W 2:30. Mr. Salton.

Fundamentals of computer organization and the representation of structured operands in computers. Information flow during instruction execution; addressing structures, symbol table techniques. Algorithms for the manipulation of arrays, trees, strings, lists. Programming language structure; recognition and analysis systems. Time-sharing computer organization, paging, segmenting and core management.

412. COMPUTER LANGUAGE AND COMPILERS

Spring term. Credit four hours. Prerequisite: 411 or consent of the instructor. M W F 1:25. Mr. Wegner.

Concerned with the theory and techniques of programming languages and systems for large scale digital computer systems. Topics include comparison of structure and form of assemblers, interpreters, compilers and list processors; formal definition of algorithmic languages and techniques used in compilation. Students will design and implement several simple languages during the term.

413. SYSTEMS PROGRAMMING

Fall term. Credit four hours. Prerequisite: 412 or consent of the instructor. M W F 1:25. Mr. Wegner.

Brief review of batch process programming systems, their components, operating characteristics, user services and their limitations. Implementation

techniques for parallel processing of I/O and interrupt handling. Overall structure of multiprogramming systems on large-scale multiprocessor hardware configuration. Details on addressing techniques, core management, file system design and management, system accounting, and other user-related services. Command languages and the embedding of subsystems. Operating characteristics (parameters) of large-scale systems.

[417. ADVANCED INFORMATION PROCESSING]

Fall term. Credit four hours. Prerequisite: 401 or equivalent experience. T Th 9:05, W 2:30. Not offered in 1967–68.

420. COMPUTER APPLICATIONS OF NUMERICAL ANALYSIS

Fall term. Credit four hours. Prerequisites: Mathematics 222 or 294 and Computer Science 311 or equivalent programming experience. M W F 9:05. Mr. Brown.

Modern computational algorithms for the numerical solution of a variety of applied mathematics problems are presented and students solve current representative problems by programming each of these algorithms to be run on the computer. Topics include numerical algorithms for the solution of linear systems; finding determinants, inverses, eigenvalues and eigenvectors of matrices; solution of a single polynominal or transcendental equation in one unknown; solution of systems of nonlinear equations; acceleration of convergence; Lagrangian interpolation and least squares approximation for functions given by a discrete data set; differentiation and integration; solution of ordinary differential equations: initial value problems for systems of nonlinear first order differential equations, two-point boundary value problems; partial differential equations: finite difference grid technique for the solution of the Poisson equation.

421–422. NUMERICAL ANALYSIS

Throughout the year. Credit four hours a term. Prerequisite: Mathematics 412 or 416 or 422. M W F 9:05. Mr. Walker, Mr. Brown.

A mathematically rigorous treatment of numerical analysis. Covers the topics of Computer Science 420 in a more complete fashion with emphasis on careful analytical derivation of algorithms, proofs of convergence, and error analysis. Includes some computer programming projects.

435. INFORMATION ORGANIZATION AND RETRIEVAL

Spring term. Credit four hours. Prerequisite: 401 or equivalent. T Th 9:05, occasionally W 2:30. Mr. Salton.

Covers all aspects of automatic language processing on digital computers, with emphasis on applications to information retrieval. Analysis of information content by statistical, syntactic, and logical methods. Dictionary techniques. Automatic retrieval systems, question-answering systems. Evaluation of retrieval effectiveness.

[441. HEURISTIC PROGRAMMING]

Spring term. Credit four hours. Prerequisites: Computer Science 401 and 411. Not offered in 1967–68.

485. THEORY OF AUTOMATA I

Fall term. Credit four hours. Prerequisite: Computer Science 401, Mathematics 481, or consent of the instructor. M W F 11:15. Mr. Hartmanis.

Automata theory is the study of abstract computing devices, their classification, structure, and computational power. Topics include finite state auto-

mata, regular expressions, decomposition of finite automata and their realization, Turing machines and their computation power.

486. THEORY OF AUTOMATA II

Spring term. Credit four hours. Prerequisite: 485 or consent of the instructor. M W F 11:15. Mr. Hartmanis.

Topics include context-free and context-sensitive languages and their relation to push-down and linearly-bounded automata. Quantitative aspects of Turing machine computations: time and memory bounded computations with applications to language processing and classification of other automata and computations.

487. FORMAL LANGUAGES

Fall term. Credit four hours. Prerequisite: 401. M W F 11:15. Mr. Hopcroft.

A study of formal languages, their processing and processors. Topics include regular, context-free, and context-sensitive languages; their recognition, parsing, algebraic properties, decision problems, recognition devices, and applications to computer and natural languages.

[488. THEORY OF EFFECTIVE COMPUTABILITY]

Spring term. Credit four hours. Prerequisite: Computer Science 401, 485, Mathematics 481, or consent of the instructor. Not offered in 1967–68.

Turing machines and Church's Thesis, universal Turing machines, unsolvability of the halting problem. Recursively enumerable sets, productive and creative sets, relative computability, the recursion theorem, Post's problem. Computational complexity hierarchies.

[521. NUMERICAL ANALYSIS OF LINEAR AND NONLINEAR SYSTEMS OF EQUATIONS]

Spring term. Credit four hours. Prerequisites: Mathematics 521 and Computer Science 422. M W F 9:05. Mr. Brown. Not offered in 1967–68.

Topics include recent methods for the solution of linear systems and eigenvalue, eigenvector determination; global convergence theorems for nonlinear systems, Newton-Kontorovich theory and its variations; function minimization.

523. NUMERICAL SOLUTION OF ORDINARY DIFFERENTIAL EQUATIONS AND INTEGRAL EQUATIONS

Fall term. Credit four hours. Prerequisites: Mathematics 427 and Computer Science 422. M W F 2:30.

Topics include solution of n-th order nonlinear initial value problems and boundary value problems; single step methods; predictor-corrector techniques; stability, accuracy and precision of methods; eigenvalue problems; solution of integral equations having constant or variable limits: finite difference and iterative methods; singular and nonlinear integral equations.

525. NUMERAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS

Spring term. Credit four hours. Prerequisites: Mathematics 428 and 521, and Computer Science 523. M W F 2:30.

General classification; solution by method of characteristics; finite-difference methods for hyperbolic and elliptic equations; parabolic equations in two dimensions; direct solution of elliptic finite-difference equations; iterative methods for the solution of elliptic equations; block methods for large systems; singularities in elliptic equations; stability in relation to initial value problems and nonlinear discretization algorithms.

527. NUMERICAL METHODS IN APPROXIMATION THEORY

Sprng term. Credit four hours. Prerequisites: Mathematics 521 and Computer Science 422. M W F 9:05. Mr. Walker.

L_p norms; least-square approximation and orthogonal functions; Tchebycheff, asymptotic, rational and continued fraction approximations; the quotient-difference algorithm; methods of descent and ascent.

[587. COMPUTATIONAL COMPLEXITY]

Fall term. Credit four hours. Prerequisite: Computer Science 486 or 488 or consent of the instructor. M W F 11:15. Not offered in 1967–68.

590. SPECIAL INVESTIGATIONS IN COMPUTER SCIENCE

Throughout the year. Credit and sessions to be arranged.

Offered to qualified students individually or in small groups. Directed study of special problems in the field of computer science. (Register only with the registration officer of the department.)

591. COMPUTER SCIENCE GRADUATE SEMINAR

Throughout the year. Credit one hour. For graduate students interested in computer science. Th 4:30–6:00. Staff, visitors, and students.

A weekly meeting for the discussion and study of important topics in the field.

661. SEMINAR IN NATURAL LANGUAGES

Spring term. One two-hour meeting per week to be arranged. Seminar given in conjunction with the Linguistics Department. Mr. Coynad.

Application of computer techniques to natural language processing.

[621. SEMINAR IN NUMERICAL ANALYSIS.]

One term. Credit four hours. Prerequisite: consent of the instructor. Not offered in 1967–68.

[681. SEMINAR IN AUTOMATA THEORY.]

One term. Credit four hours. Prerequisite: consent of the instructor. Not offered in 1967–68.

DATA PROCESSING SYSTEMS (Business and Public Administration 901)

Spring term. Credit three hours. M W F 8.

An introductory course in modern data processing systems for graduate students not in computer science.

ADVANCED DATA PROCESSING SYSTEMS (See Operations Research 9582)

Fall term. Credit three hours. Prerequisite: Computer Science 401, or BPA 901, or consent of the instructor.

Concerned with design of integrated data processing systems for operational and financial control.

DIGITAL SYSTEMS SIMULATION (See Operations Research 9580)

Fall term. Credit three hours. Prerequisite: Computer Science 401 and a course in probability.

The use of a program for a digital computer to simulate the operating characteristics of a complex system in time.

SWITCHING SYSTEMS I (See Electrical Engineering 4587)

Fall term. Credit three hours. Prerequisite: Electrical Engineering 4322 or consent of the instructor.

Topics include switching devices, realization of combinational switching circuits, sequential circuits, arithmetic units in a digital computer.

SWITCHING SYSTEMS II (See Electrical Engineering 4588)

Spring term. Credit three hours. Prerequisite: Electrical Engineering 4587 or equivalent.

A continuation of Switching Systems I.

ELECTRICAL ENGINEERING

Faculty: Paul D. Ankrum, Joseph M. Ballantyne, Henry D. Block, Ralph Bolgiano, Neil M. Brice, Nelson H. Bryant, Herbert J. Carlin, G. Conrad Dalman, Nicholas DeClaris, Lester F. Eastman, William H. Erickson, Donald T. Farley, Terrence L. Fine, Thomas Gold, Juris Hartmanis, Clyde E. Ingalls, Frederick Jelinek, Edwin F. Johnson, Myunghwan Kim, Charles A. Lee, Richard L. Liboff, Simpson Linke, Lee A. MacKenzie, Henry S. McGaughan, Paul R. McIsaac, Charles W. Merriam III, Wilbur E. Meserve, John A. Nation, Benjamin Nichols, Robert E. Osborn, Christopher Pottle, Edwin L. Resler, Jr., Joseph L. Rosson, Gian-Carlo Rumi, Neil J. A. Sloane, Howard G. Smith, Ravindra N. Sudan, Chung-Liang Tang, James S. Thorp, Hwa Chung Torng, Norman M. Vrana, Leonard S. Wagner, Charles B. Wharton, George J. Wolga, Stanley W. Zimmerman.

Field Representative: Wilbur E. Meserve, 230 Phillips Hall

MAJOR AND MINOR SUBJECTS

Electrical Engineering
Electrophysics
Electrical Systems

Considerable latitude is allowed in the selection of the minor subjects, provided that the entire program shows a unified purpose.

Adequate work in advanced physics and mathematics is required of candidates for the degree of Ph.D. At least one of the two minor subjects must be chosen outside the Field of Electrical Engineering.

The appropriate major and minor subjects listed above define broad areas in the Field of Electrical Engineering within which a student may plan a graduate program which best suits his needs. In addition to the formal courses listed below, members of the faculty are prepared to guide individual students in special topics and to arrange seminars for students interested in closely related lines of study and research. Proficiency is expected in all phases of the graduate program.

ADMISSION REQUIREMENTS. Though the Graduate Record Examination is not required in the Field of Electrical Engineering, applicants are urged to take this examination, submitting its results along with their application for graduate work.

As prerequisite for graduate work leading to the degree of M.S. or Ph.D. with a major in the Field of Electrical Engineering, the candidate should have had the equivalent of the fundamental work required by an accredited undergraduate curriculum in the area of his major subject. The candidate must

also supply definite evidence of scholarly interest and aptitude for advanced study.

LANGUAGE REQUIREMENTS. There is no foreign language requirement for the M.S. degree.

For admission to Ph.D. candidacy, a student is required to demonstrate proficiency in one modern foreign language.

EXAMINATIONS. The Field of Electrical Engineering requires that every Ph.D. student, prior to taking the Admission to Candidacy Examination, complete successfully a qualifying examination.

For the Master of Science Degree a final examination is required.

Examinations as required by the Graduate School (see pages 9–10) are conducted by the student's Special Committee.

FACULTY RESEARCH INTERESTS. Members of the faculty in the Field of Electrical Engineering are especially interested in directing graduate research in the following areas:

ELECTRICAL ENGINEERING. Applied mathematics; biomedical electronics; electrical measurements; ionospheric studies; magnetohydrodynamics; materials science; physics of maser and laser systems; radio astronomy; satellite instruments.

ELECTRICAL SYSTEMS. Analysis and synthesis of time-variable and nonlinear systems; switching systems; control systems analysis, optimization and adaptation; conversion, transmission and control of electric energy; information theory; random processes; signal processing, system theory.

ELECTROPHYSICS. Lasers; microwave electronics; plasma physics; quantum electronics; radiophysics.

It is not desirable, nor is it intended, that the boundaries between these areas be too rigidly defined. Rather, every effort is made to allow each student to pursue a program designed to give him a period of broad advanced study. To this end, work in such subjects as applied physics, astronomy, biological science, engineering materials, fluid mechanics, or thermodynamics may be considered as partially fulfilling the requirements for a major or minor in Electrical Engineering, even though these subjects are not under the direct jurisdiction of the faculty of the School of Electrical Engineering.

Financial Aid

In addition to several University-wide fellowships, the following are available for Electrical Engineering degree candidates:

John McMullen Graduate Fellowship. $2,000 plus tuition and fees.

AEC Traineeships in Nuclear Science and Engineering. Stipends similar to NSF and NASA Traineeships.

IBM Fellowship. $1,800 plus tuition and fees. Provision for an additional $700 if candidate is married and has at least one child. Open to candidates in the Fields of Applied Physics, Electrical Engineering, and Operations Research.

NASA Traineeships. Available on a twelve-month basis in amounts of $2,400 to $2,800 plus tuition and fees. A $600 allowance is available if recipient is married and has one or more children. Open to United States citizens.

National Science Foundation Traineeships. Available on a nine- or twelve-month basis. Stipends are $2,400, $2,600, and $2,800 on a twelve-month basis for first, second, and third years respectively. Tuition and fees will be paid, and $500 per dependent is allowed on the twelve-month basis. Candidates must be United States citizens.

Xerox Fellowship. $3,500 plus tuition and fees. Open to students in the first year of graduate study majoring in any of the Fields encompassed by the Materials Science Center, such as Electrical Engineering, Applied Physics, Materials Science and Engineering, and Theoretical and Applied Mechanics.

Michael Faraday and James Clerk Maxwell Fellowships of Cornell Aeronautical Laboratory. Range from $2,000 up plus tuition and fees. Provision for an additional $600 if recipient is married.

United States Steel Foundation Fellowship. $1,500 plus tuition and fees. Provision for an additional $600 if recipient is married.

Charles Bull Earle Memorial Graduate Fellowship. $600 plus tuition and fees. The stipend may be supplemented in special cases.

There are also several teaching fellowships and research assistantships available paying $2,000 and tuition and fees with adjustments upward to $2,800 for additional qualifications and experience. Research assistantships may be granted for full-time summer work paying $1,000.

A prospective graduate degree candidate is invited to direct his inquiries to the Graduate Field Representative for Electrical Engineering, 230 Phillips Hall.

Professional Degree

The Master of Engineering degree is the only professional engineering degree offered by Cornell University. Admission to the Master of Engineering (Electrical) degree program is open to persons who have been granted Bachelor's degrees, or the equivalent, and who have sufficient training to indicate that they can profitably study the advanced courses offered for these students in the School of Electrical Engineering. The purpose of this degree program is to offer depth of study in both comprehensive and specialized electrical engineering subjects, and to offer study extending the abilities of the electrical engineer to other areas.

In addition to the general requirements for the degree (see page 178), a further requirement for the Master of Engineering (Electrical) is a minimum of two two-course sequences in advanced electrical engineering (chosen from a designated list).

Graduates of Cornell University with a Bachelor of Electrical Engineering degree may be granted up to fifteen hours of credit for advanced courses taken during the fifth undergraduate year, provided they enter the M.Eng.(E). program not later than the fall term following the sixth anniversary of their receiving the B.E.E. degree. For those students who are granted fifteen credit hours of advanced standing, the requirement is six credit hours in the School of Electrical Engineering rather than two two-course sequences, and the design requirement may be waived.

Elective and Graduate Courses

Of the following elective and graduate courses, certain ones may not be offered every year if the demand is considered to be insufficient.

THEORY OF SYSTEMS AND NETWORKS

4501. SYSTEMS WITH RANDOM SIGNALS

Credit four hrs. Fall. Three lectures, one recitation. Prerequisite: 4402 or equivalent. Mr. McGaughan.

Linear systems and signals; probability and random variables; random processes in communication systems; spectral analysis of random processes; filtering of random signals; band-pass signals and noise; envelope detection of signals and noise; post detection filtering; nonlinear receiver operations; modulation systems; time and frequency multiplex systems; noise in analog modulation systems.

4502. STATISTICAL ASPECTS OF SYSTEM ANALYSIS

Credit four hrs. Spring. Three lectures, one recitation. Prerequisite: 4501. Mr. McGaughan.

Digital transmission systems; the discrete transmission channel; elements of information transmission and coding; information capacity; system optimization; linear least squares prediction and smoothing; matched filters; optimum receivers; hypothesis testing; parameter estimation; the matched filter and the correlation receiver; wave-form systems and signal design; error probabilities and error bounds for various systems.

4503. THEORY OF LINEAR SYSTEMS I

Credit four hrs. Fall. Three lectures. Prerequisite: 4401 or consent of the instructor. Mr. DeClaris.

Introduction to linear system theory through an axiomatic approach and its applications to control and information processing. Characterization of linear lumped parameter systems: integral, differential and normal forms. The state concept: state vectors, nodes in linear systems, the notions of controllability and observability. Analysis of time-invariant and time-varying linear systems and their properties. Signal spaces, duality concepts. Discrete-time linear systems. Stability of motion.

4504. THEORY OF NONLINEAR SYSTEMS I

Credit four hrs. Spring. Three lectures. Prerequisite: 4503 or 4501 or 4571 or consent of the instructor. Mr. DeClaris.

Lagrangian formulation. Analysis of first and second order nonlinear systems with applications. Phase plane analysis of autonomous systems; singular points, limit cycles, and equilibrium states; theories of Bendixson, Lienard, and Poincare; relaxation behavior in the phase plane; perturbation theory, existence, convergence and periodicity of perturbation series; the methods of van der Pol, and Krylov and Bogoliubov. Forced nonlinear systems, harmonics, subharmonics, jump phenomena, and frequency entrainment; periodic systems, Floquet theory, Mathieu-Hill theory, applications to the stability of nonlinear systems and to parametrically-excited systems.

4505–4506. OPTIMIZATION AND APPROXIMATION TECHNIQUES I AND II

Credit four hrs. Fall and spring. Three lectures. Prerequisites: 4402 and current registration in 4503 or consent of the instructor. Mr. Thorp or Mr. Merriam.

Optimization and approximation techniques used in the synthesis of systems and signals, with applications in control and communication. Signal approximation problems; Kautz filters, measurement of expansion coefficients, complementary filters. Examples of signal approximation problems

in biological and electrical systems. Optimum pole positions for exponential approximation. Computational methods for parameter optimization and approximation problems. Formulation of deterministic control optimization problems; minimal time, minimal fuel, regulator problems. Introduction to variational methods. Solution of two-point boundary-value problems by control vector iteration. Statistical optimization problems. Synthesis of optimal filters and feedback controllers.

4507–4508. RANDOM PROCESSES IN ELECTRICAL SYSTEMS

Credit four hrs. Three lectures. Mr. Fine or Mr. Jelinek.

The concepts of randomness and uncertainty and their relevance to the design and analysis of electrical systems. An axiomatic characterization of random events. Numerically valued events: random variables and random vectors. Distribution functions and densities. Functions of random vectors. Expectation and measures of fluctuation. Moment and probability inequalities. Properties and applications of characteristic functions. Convergence of sequences of random variables: laws of large numbers and central limit theorems. More general collections of random variables: random processes. Random processes as signal or system models and their specification. Sample function behavior. Markov processes, particularly chains and the Poisson process. Stationarity and ergodicity. The Gaussian process. Wide sense stationary processes: correlation functions, spectra. Representations of random processes. Transformations of random processes by nonlinear devices and filters. Optimum filtering theories.

4571–4572. NETWORK ANALYSIS AND SYNTHESIS I AND II

Credit three hrs. per term. Throughout the year. Three lectures. Mr. Carlin.

Scattering, immittance, and hybrid network formalisms discussed and applied to network analysis and power transfer in multiport junctions. Elements of synthesis of reciprocal and nonreciprocal lumped networks including n-ports. General physical basis for network techniques in distributed systems deduced from linearity, time-invariance and power-energy constraints. Generalized bounded real and positive real functions and matrices, and the theory of physical realizability applications to propagation in nonreciprocal media, synthesis of transmission line networks, gain-bandwidth theory of active devices. At the level of Carlin and Giordano, *Network Theory: An Introduction to Reciprocal and Nonreciprocal Circuits.*

4601. THEORY OF NONLINEAR SYSTEMS II

Credit four hrs. Spring. Three lectures. Prerequisite: 4504 or consent of the instructor. Mr. Thorp.

Nonautonomous and higher order nonlinear systems with applications; representation of systems with several degrees of freedom; approximations; use of Lyapunov functions in system stability determination and design; describing functions and Aizerman's hypothesis, theory of Lur'e-Letov for nonlinear control; asymptotic expansions for the period behavior of systems under the influence of periodic external forces; method of averaging; systems with slowly varying parameters, Manley-Rowe relations; orthogonal representation of nonlinear systems; nonlinear filters and compensating systems, system optimization.

4603. THEORY OF LINEAR SYSTEMS II

Credit four hrs. Three lectures. Fall term. Prerequisite: 4503. Mr. DeClaris.

Rigorous developments of linear graph theory and of linear transformations with applications to control and communication systems. Topological prop-

erties of weighted graphs, signal-flow graphs, communication nets. Algebraic methods. Signal analysis. Functionals and properties: model making. Linear function spaces with applications to system realization, stability and sensitivity. Asymptotic expansions.

4604. UNIFIED THEORY OF ELECTROMECHANICAL SYSTEMS

Credit three hrs. Two lectures, one computation period. Prerequisite: 4441, 4442, or consent of the instructor.

Electric machines studied as networks of coupled circuits with periodically varying parameters; forces and torques in electromechanical systems; electromagnetic and electrostatic transducers; Kron's basic machine with its practical derivatives; the synchronous, induction and commutator machines in the transient and steady state; frequency response methods applied to machines.

ELECTROMAGNETIC THEORY

4511. ELECTRODYNAMICS

Credit four hrs. Fall. Three lectures. one recitation. Prerequisites: 3212 or equivalent, and coregistration in Mathematics 421 or equivalent. Mr. Liboff.

Foundations of electromagnetic theory; potential theory; Maxwell's equations; microscopic interpretation of permittivity and permeability; electromagnetic energy-momentum and stress tensors; interaction of fields with rigid and fluid conductors in motion; waves in various homogeneous, inhomogeneous, and anisotropic media, including plasmas; guiding of waves, cavities, radiation and antennas; use of Green's function, perturbation, variational, and WKBJ methods; special relativity, fields of uniformly moving and of accelerated charges, radiation reaction. At the level of Panofsky and Phillips, *Classical Electricity and Magnetism.*

4514. MICROWAVE THEORY

Credit four hrs. Spring. Three lectures, one recitation. Prerequisite: 4511 or equivalent.

Theory of passive microwave devices for propagating, storing, coupling, or radiating microwave energy, including the theory of uniform and periodic waveguides, cavities, junctions, and antennas; application of inhomogeneous, anisotropic, dispersive, or nonlinear dielectric and magnetic materials to microwave devices; circulators, isolators, tunable filters, limiters, artificial dielectrics; techniques of analysis, including use of orthogonal functions, perturbation theory, variational techniques, Green's functions, and symmetry principles.

4567. ANTENNAS AND RADIATION

Credit three hrs. Fall. Three lectures. Prerequisites: 4312 and 4401, or equivalent. Mr. Farley.

Formulation of the electromagnetic field in terms of vector and scalar potentials; radiation from elemental electric and magnetic dipoles. Linear radiators: radiation from short dipoles, small loops; resonant wire antennas; long wire antennas, linear arrays and pattern synthesis; impedance properties of wire antennas, including mutual impedance, parasitic elements; wire receiving antennas. Aperture antennas: uniqueness theorem for vector fields, equivalence and induction principles; radiation from open-ended waveguides, horn antennas, reflector antennas; Babinet's principle; slot antennas.

4568. ADVANCED ANTENNA METHODS AND PROBLEMS

Credit three hrs. Spring. Three lectures. Prerequisites: 4567 or equivalent, and 4511 or equivalent. Mr. Farley.

Huygens' principle for electromagnetic fields, application to problems of diffraction and aperture radiators; surfacewave antennas; various specialized antennas, helical, log periodic, radio astronomy systems, space and satellite systems; radiation in dielectric and plasma media, including media in motion; antenna thermodynamics.

4421–4422. ADVANCED ELECTRICAL LABORATORY

Credit four hrs. May be taken in the fall and spring consecutively or separately. One lecture, two laboratories. Prerequisite: 4322 or consent of the instructor.

Advanced experiments concerning a wide range of topics appropriate to electrical engineering, and lectures concerning experimental techniques and practical aspects of electronics. About thirty different experiments are available concerning topics of transistor and tube amplifiers, feedback, class-C amplifiers and oscillators, gyrators, doubletuned circuits, push-pull amplifiers, multivibrators, operational amplifiers, switching systems, oscillator synchronization, noise properties. microwave circuits, microwave propagation and scattering, semiconductor properties such as the hall effect and minority carrier mobility, helicone waves, Gunn and avalanche diode oscillators, lasers, propagation of electromagnetic waves, antennas, and a-c and d-c machines. The student is expected to perform three or four experiments per term, selected to meet his needs. Emphasis is placed upon independent work.

4520. GRADUATE LABORATORY

Credit three hrs. Fall normally, but either term if demand is sufficient. One laboratory.

Choice of three to five experiments in the fields of solid-state and quantum electronics, microwave electronics, vacuum and physical electronics, optics, radio and communication circuits, networks, transmission lines, antennas, propagation of electromagnetic waves, plasma physics, and electrical machinery.

ELECTRONICS

4431–4432. ELECTRONIC CIRCUIT DESIGN

Credit three hrs. per term. Throughout the year. Two lecture-recitations, one laboratory. Prerequisite: 4322. Mr. Bryant.

Design techniques for circuits used in electronic instrumentation. Circuits will be designed to provide specific functions, then constructed and tested in the laboratory. At the level of Millman and Taub, *Pulse Digital and Switching Waveforms.*

4433. SEMICONDUCTOR ELECTRONICS I

Credit four hrs. Fall. Three lectures, one laboratory. Prerequisites: 4302 and 4322. Mr. Ankrum.

Band theory of solids; properties of semiconductor materials; the physical theory of p-n junctions, metal-semiconductor contacts, and p-n junction devices; device fabrication; properties of semiconductor devices such as diodes and rectifiers, light-sensitive and light-emitting devices, field-effect and bipolar transistors, unijunction transistors, p-n-p-n devices (diodes, controlled rectifiers and switches), etc.; device equivalent-circuit models; field-effect and bipolar transistor amplifier stages. At the level of the *Semiconductor Electronics Education Committee (S.E.E.C.) Series,* Vols. 1-4.

4434. SEMICONDUCTOR ELECTRONICS II

Credit four hrs. Spring. Two lectures, two laboratories. Prerequisite: 4433. Mr. Ankrum.

A continuation of Semiconductor Electronics I with emphasis on the application of semiconductor devices as active or passive elements in circuits for use as power supplies, power controls, amplifiers, oscillators and multivibrators, pulse circuits, gates and switches, etc.; transistor noise; integrated circuits. At the level of the *S.E.E.C. Series,* Vols. 5 and 6 and *Semiconductor Controlled Rectifiers: Principles and Application of p-n-p-n Devices,* by Gentry, et al.

4531. QUANTUM ELECTRONICS I

Credit four hrs. Fall. Three lectures, one recitation-computation. Prerequisites: 4311, 4312, and Physics 443 or 4411. Mr. Wolga.

A detailed treatment of the physical principles underlying microwave, and optical masers and related fields. Topics will include a brief review of quantum mechanics and the theory of angular momentum; spectroscopy of free atoms and ions with particular emphasis on the application of the results to neutral and ionized noble gas masers; theory of interaction of radiation and matter; quantum theory of coherence; a thorough study of the steady-state and dynamic characteristics of microwave and optical masers.

4532. QUANTUM ELECTRONICS II

Credit four hrs. Spring. Three lectures, one recitation-computation. Prerequisite: Quantum Electronics I or consent of the instructor. Mr. Wolga.

A continuation of the treatment of the physical principles underlying masers and related fields. Topics will include a consideration of microwave and optical spectroscopy of impurity ions in solids with particular emphasis on the application of the results to microwave and optical solid state masers; density matrix and its applications in the study of masers and related problems; nonlinear optical phenomena and multiplephoton processes; interaction of intense light waves with molecular vibrations and elastic waves; theory and properties of molecular and semiconductor masers; characteristics of optical resonators.

4535. SEMICONDUCTOR DEVICES I

Credit four hrs. Fall. Three lectures. Prerequisite: 4412 or equivalent. Mr. Dalman.

A study of the physical theories underlying semiconductor devices with emphasis on low frequency operation (below 1,000 GHz). Devices based on the tunnel effect: tunnel diodes, field emitter cathodes, thin film resistors. Devices based on charge flow across semiconductor-semiconductor contacts: p-n diodes, avalanche diodes, transistors, field-effect transistors, unipolar transistors. Devices based on metal-semiconductor contacts: Shottky diode, Shottky triode. Emphasis is placed on determining the factors determining performance capabilities. Equivalent circuits are developed. The student will carry out either a term laboratory project or prepare a term paper on an appropriate contemporary topic. The course is presented at the level of Moll, *Physics of Semiconductors* (McGraw-Hill) and of current papers published in the *IEEE Transactions on Electron Devices.*

4536. SEMICONDUCTOR DEVICES II

Credit four hrs. Spring. Three lectures. Prerequisite: 4551 or equivalent. Mr. Dalman.

A study of the physical theories underlying semiconductor devices with

emphasis on high frequency operation (above 1,000 GHz). The approaches to the analysis to be studied are: Ballistic analysis, electronic-network analysis (Llewellyn-Peterson), space-charge wave and coupled-mode analysis. Devices studied include: avalanche microwave diode (Read diode), microwave transistors, tunnel diodes, Gunn oscillators, injection lasers. Emphasis is placed on determining the factors that determine the performance capabilities. Equivalent circuits are developed. The student will carry out either a term laboratory project or prepare a term paper on an appropriate contemporary topic. The course is presented at the level of current papers published in the *IEEE Transactions on Electron Devices.*

4538. ELECTROMAGNETIC PROPERTIES OF SOLIDS

Credit four hrs. Spring. Three lectures, one recitation. Prerequisites: Phys. 454, or 4412 and 4511 (Electrodynamics), or consent of the instructor. Mr. Ballantyne.

Microscopic interpretation of complex permittivity and permeability: electronic, atomic, orientation and space charge polarization; interaction of elementary magnetic moments; dielectric dispersion via resonance and relazation, plasma resonance; quantum theory of dielectric constant; local internal field and spontaneous ordering; introductory lattice dynamics, lattice frequency spectrum, introductory group theory and application to derivation of selection rules for infrared and Raman active normal modes; extended frequency analysis of vibrational spectra.

4631. ADVANCED MICROWAVE ELECTRONICS

Credit four hrs. Fall. Three lectures, one computation period. Prerequisite: 4552. Mr. Eastman.

Physical theory of waveguides and cavities containing gaseous and solid state plasma, including dispersion, periodicity, modes, impedance, coupling and perturbation; microwave physics of gaseous and solid state plasmas, and drifting electrons; active effects of drifting electrons, charge avalanching, transferred electrons as in Gunn effect, and of microwave acoustic and Helicon waves.

POWER SYSTEMS AND MACHINERY

4441. CONTEMPORARY ELECTRICAL MACHINERY I

Credit three hrs. Fall. Two lecture-recitation periods, one laboratory-computation period. Prerequisite: 4302. Mr. Osborn.

Emphasis on engineering principles. Real and reactive power requirements of core materials with symmetrical and with biased magnetizing forces; analysis and characteristic prediction of high-efficiency transformers; magnetic amplifiers, energy transfers among electric circuits, magnetic fields and mechanical systems; control of magnetic field distribution by reluctance and winding distribution; travelling fields from polyphase excitation; elementary idealized commutator-type, asynchronous, and synchronous machines.

4442. CONTEMPORARY ELECTRICAL MACHINERY II

Credit three hrs. Spring. Two lecture-recitation, one laboratory-computation period. Prerequisite: 4302. Mr. Osborn.

Emphasis on engineering principles. Production of air-gap magnetic fields; elementary and idealized rotating machines; steady-state and transient characteristics of realistic rotating machines; a-c commutator-type single-phase motors; polyphase synchronous, and single phase induction machines; recently developed types: Saturistor motor, self-excited a-c generators; mis-

cellaneous rotary devices; Hysteresis motor, selsyns, amplidynes, frequency converters.

4443. POWER SYSTEM EQUIPMENT

Credit three hrs. Fall. Two lectures, one computation period. Prerequisite: 4302. Mr. Zimmerman.

System equipment and control parameters are studied. Test requirements for electrical apparatus for conventional and nuclear electrical power production and distribution are considered. Prime movers, generators and their accessories, switchgear, protective devices, power transformers, converters, towers, conductors, regulating devices, and data gathering and computer control systems are analyzed. Inspections of nearby station equipment are planned to supplement classroom work.

4444. HIGH VOLTAGE PHENOMENA

Credit three hrs. Spring. Prerequisite: 4302. Mr. Zimmerman.

The study of problems of the normal operation of power systems at very high voltages, of the abnormal conditions imposed by lightning, of the methods employed to assure proper operation of power systems and apparatus under high-voltage conditions, and of the devices available for laboratory testing of equipment under actual or simulated conditions. An invitation to visit electrical manufacturing test facilities is usually accepted. Considerable attention is given to dielectric behavior and testing techniques.

4445–4446. ELECTRIC ENERGY SYSTEMS I AND II

Credit four hrs. per term. Three lecture-recitation-computations. Prerequisites: 4422 or 4302 and consent of the instructor. Mr. Linke.

The physical and engineering principles underlying steady-state and transient operation and control of modern electric-power systems, with emphasis on the characteristics of major power-system parameters. Theory of electromechanical energy converters, power transformers, conventional transmission lines and cables, high-voltage-direct-current systems, power networks and other power-system components; use of the digital computer as a dynamic "laboratory" model of a complex power system for load flow, fault, transient stability and economic-analysis studies. Laboratory-computing periods will include selected experiments with electromechanical energy converters. At the level of Stevenson, *Elements of Power System Analysis*, 2nd Edition.

RADIO AND PLASMA PHYSICS

4461. WAVE PHENOMENA IN THE ATMOSPHERE

Credit three hrs. Fall. Three lecture-recitation periods. Prerequisites: 4302 and 4312. Mr. Bolgiano.

An elementary treatment of wave phenomena in the atmosphere of the earth including gravity waves, planetary waves, acoustic waves, radio waves, and plasma waves; attention is directed to the role of these phenomena in various atmospheric processes and engineering problems, such as weather, pollution, radio communication, atomic fallout.

4462. RADIO ENGINEERING

Credit three hrs. Spring. Three lecture-recitation periods. Prerequisite: 4312 and 4402. Mr. Bolgiano.

A study of electrical systems for communication, control, detection, and other purposes, in which radiowaves (wireless) play a central role: system functions, including generation, modulation, transmission, reception, and de-

modulation; guidance, radiation, and propagation of radiowaves, including transmission lines and waveguides, antenna systems, and the effects of atmospheric inhomogeneity; system design problems.

4561. INTRODUCTION TO PLASMA PHYSICS

Credit three hrs. Fall. Three lectures. Prerequisites: 4311 and 4312 or equivalent. Mr. Sudan.

Plasma state; motion of charged particles in fields; adiabatic invariants, collisions, coulomb scattering; Langevin equation; transport coefficients, ambipolar diffusion, plasma oscillations and waves; hydromagnetic equations; plasma confinement, energy principles and macroscopic instabilities; test particle in a plasma; elementary applications. At the level of Longmire, *Elementary Plasma Physics*.

4562. WAVES IN PLASMAS

Credit three hrs. Spring. Three lectures. Prerequisite: 4561. Mr. Nation.

Magnetoactive cold plasma theory, CMA diagrams, plasma and cyclotron waves, whistlers, hydromagnetic waves, bounded plasmas, shocks, radiation; applications to laboratory and natural phenomena. At the level of the first half of Stix, *Theory of Plasma Waves*.

4564. ADVANCED PLASMA PHYSICS

Credit three hrs. Spring. Three lectures. Prerequisite: 4561. Mr. Sudan.

Boltzmann and Vlasov equations; moments of kinetic equation, Chew-Goldberger-Low theory, waves in hot plasmas, Landau damping, instabilities due to anisotropies in velocity space, gradients in magnetic field, temperature and density, etc.; effects of collisions and Fokker-Planck terms; high frequency conductivity and fluctuations, quasi-linear theory; nonlinear wave interaction, weak turbulence and turbulent diffusion.

4565–4566. RADIOPHYSICS OF THE ATMOSPHERE I AND II

Credit three hrs. each term. Fall and spring. Prerequisites: 4312 and 4401, or equivalent. Mr. Brice.

Structure of the earth's atmosphere, with particular emphasis on the use of radio waves as diagnostic tools. The course will include such topics as subionospheric propagation; propagation in the ionosphere including the Luxemburg effect and Faraday rotation; whistler-mode propagation, ion effects and ion whistlers; the CMA diagram, Astrom's equation, group velocity in anisotropic media and ray tracing; full wave solutions for slowly varying media; thermal effects including ion-acoustic waves, damping and growth of waves; radar in the ionosphere including scatter from turbulent and thermal fluctuations.

4661. KINETIC EQUATIONS

Credit three hrs. Fall. Three lectures. Prerequisites: Physics 561 and 562, or permission of the instructor. Mr. Liboff.

Designed for students wishing a firm foundation in fluid dynamics, plasma kinetic theory, and nonequilibrium statistical mechanics. Brief review of classical dynamics. The concept of the ensemble and the theory of the Liouville equation. Prigogine and Bogoliubov analysis of the BBKGY sequence. Chapman-Kolmogorov analysis of Markovian kinetic equations. Derivation of fluid dynamics. Kinetic formulation of the stress tensor. Boltzmann, Krook, Fokker-Planck, Landau and Balescu-Lenard equations. Properties and theory of the Linear Boltzmann collision operator. Chapman-Enskog and Grad methods of solution of the Boltzmann equation. Equilibrium prescription of

the approach to equilibrium. Coarse graining and ergodic theory. At the level of Prigogine, *Nonequilibrium Statistical Mechanics.*

COMMUNICATIONS

4472. INTRODUCTION TO ALGEBRAIC CODING

Credit three hrs. Spring. Three lectures. Prerequisite: Math 293 or equivalent. Mr. Sloane.

Intended for students interested in information theory or digital systems. Codes for correcting errors in data transmission or processing: Group codes, Hamming codes, Bose-Chaudhuri codes. Bounds on performance. Codes for data compression and storage: Variable-length codes, prefix codes. Codes for synchronization and their application to location of distant objects by radar. Analysis of these codes in terms of the underlying algebraic theory. Implementation by sequential machines. The algebraic theory (groups, fields, 'etc.) will be developed as needed.

4673. PRINCIPLES OF ANALOG AND DIGITAL COMMUNICATION

Credit four hrs. Fall. Three lectures. Prerequisite: 4508 or consent of the instructor.

Uses the fundamentals of information theory, signal theory, and statistical estimation and decision theory to formulate approaches to the solution of problems arising in digital and analog communication. Particular topics are: receiver and signal design, probability of error, capacity, threshold effects for the additive Gaussian channel. Extensions to the additive Gaussian channel: Feedback, random gain and phase, diversity. Time-variant Gaussian channels; receiver and signal design, probability of error, and capacity. At the level of Viterbi, *Principles of Coherent Communication.*

4674. TRANSMISSION OF INFORMATION

Credit four hrs. Prerequisite: 4507, or Mathematics 571, or consent of the instructor.

Applies information theory to the analysis and design of communication systems. Selection of fidelity criteria for accurate and efficient transmission of information. Efficient representation of outputs of message sources. The entropy measure and its properties. Encoding for reliable communication through discrete memoryless noisy channels. Rate of information transmission and the probability of decoding error, channel capacity. Systematic codes and the instrumentation problem. Sequential decoding. Coding and decoding for the band-limited Gaussian channel. At the level of F. Jelinek, *Probabilistic Information Theory.*

4676. DECISION AND ESTIMATION THEORY FOR SIGNAL PROCESSING

Credit four hrs. Fall. Three lectures. Prerequisite: concurrent registration in 4507 or Mathematics 571. Mr. Fine.

An examination of selected decision or estimation problems encountered in the design and analysis of radar/sonar target discrimination, signal demodulation, and pattern classification systems. The hypotheses of risk and uncertainty, the role of objectives, criteria for evaluating decision or estimation, procedures and characteristics of such procedures. Additional topics, drawn from the fields of parametric and nonparametric statistics, empirical time series analysis, game theory, and nonprobabilistic decision or estimation procedures, will be treated as required for the resolution of the selected problems.

COMPUTING SYSTEMS AND CONTROL

4481–4482. FEEDBACK CONTROL SYSTEMS

Credit four hrs. Fall and spring. Prerequisite: 4302 or consent of the instructor. Mr. Kim.

Principles of feedback control systems with emphasis on methods of analysis and synthesis to meet prescribed performance criteria. One-sided Laplace transform applications; electronic, electromechanical, electrohydraulic, and pneumatic components; cascade and feedback compensation of linear control systems. Common physical nonlinearities encountered in control systems; phase plane and describing function; nonlinear compensation; dual mode systems; relay control systems. Z-transform; analysis of sampled data systems; digital compensation; optimization of sampled data systems. Laboratory work consists of experiments in: Components, transient and frequency response measurements; compensation on linear and nonlinear control systems; simulation, design and optimization of control systems by analog and digital computers; projects of the student's choice. At the level of *Control System Analysis and Synthesis,* by D'azzo and Houpis.

4483. ANALOG COMPUTATION

Credit four hrs. Fall. Two lectures, one laboratory. Prerequisites: concurrent registration in 4401 or an equivalent background, and consent of the instructor. Mr. Vrana.

Concepts and principles of analog computation and simulation as applied to engineering analysis and design. Linear, time varying, and nonlinear differential equations. Automatic iterative and basic optimization techniques using digital logic. Laboratory work with general-purpose analog computers, some equipped with patchable digital logic. Develops fundamental ideal to include subjects at the level of Levine, *Methods of Solving Engineering Problems Using Analog Computers.*

4485. ALGEBRAIC FOUNDATION FOR SWITCHING SYSTEMS

Credit three hrs. Three lectures. Prerequisite: At least coregistration in 4487.

Presentation of algebraic concepts essential for studies in switching systems, with emphasis on engineering applications. Topics include: sets and devices; alphabets, words and languages; mapping; relations; decomposition of sets and circuit configuration; lattices; algebraic operations and their properties, the interpretation of device terminal characteristics; semigroups, simple sequential circuits and their properties; groups, quotient groups, homomorphism and other theorems, decomposition of sequential circuits, linear sequential circuits; rings, Boolean ring and switching algebra; modules and their applications in system analysis.

4487. SWITCHING SYSTEMS I

Credit three hrs. Fall. Two lectures, one laboratory. Prerequisite: 4322.

Switching algebra; switching devices; logical formulation and realization of combinational switching circuits; minimization aids; number representation and codes; simple memory devices; synchronous sequential circuits; counters; shift registers and arithmetic units in a digital computer.

4488. SWITCHING SYSTEMS II

Credit three hrs. Spring. Three lectures. Prerequisite: 4487 or equivalent.

Synchronous and asynchronous sequential circuits, formulation and optimization; large-scale memory units, selection and control; further discussion of arithmetic units; integrated study of switching systems including general-

purpose digital computer, control switching, and communication switching; introduction to the general theory of learning machines.

4589. AUTOMATA (COMPUTER SCIENCE 385)

Credit three hrs. Spring. Three recitations. Prerequisites: Math 293–294, or Math 221–222, or equivalent.

Both the engineering and mathematical aspects of automata will be introduced. Examples of mathematical topics: finite-state machines, neural nets, input-output machines. Turing machines, computability. Examples of engineering topics: Machines that learn, adaptive systems, pattern recognition, self-reproducing and self-repairing machines, system reliability, threshold logic systems, biological models, heuristic programming, industrial technological applications, progress in devices, automatic language translation, cybernetics and robots.

4681. RANDOM PROCESSES IN CONTROL SYSTEMS

Credit four hrs. Fall. Three lectures. Prerequisites: 4574 and 4584.

Prediction and filtering in linear control systems; Gaussian-Markov sequence, Gaussian-Markov process, prediction problem, Hamiltonian formulation of filtering problem, generalized Wiener filtering, stochastic optimal and adaptative control problems. Selected topics: Bayes decision rule, min-max policy, maximum likelihood estimate, control of systems with uncertain statistical parameters; stochastic differential equations, optimal nonlinear filtering; Gaussian input describing function, stability of control systems with random parameters.

GENERAL

4591 and 4592. PROJECT

Credit three hrs. Fall and spring.

Individual study, analysis, and usually experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing his project; an engineering report on the project is required.

4593. FUNDAMENTALS OF ACOUSTICS

Credit four hrs. Fall. Three lectures, one laboratory. Mr. Ingalls.

Given at the level of *Fundamentals of Acoustics,* by Kinsler and Frey. Intended for first year graduate students and qualified seniors. Vibrations in strings, bars, membranes and plates; plane and spherical acoustic waves; transmission, reflection, absorption, resonators, filters; loudspeakers and microphones; speech, hearing, and noise; architectural acoustics; ultrasonic and sonar transducers; underwater acoustics.

4595–4596. ELECTRICAL ENGINEERING DESIGN

Credit three hrs. per term. Fall and spring.

Offered for students enrolled in the M.Eng.(E.) program. Utilizes real engineering situations in which to present fundamentals of engineering design.

4690–4699. SPECIAL TOPICS IN ELECTRICAL ENGINEERING

Credit one to three hrs.

Seminar, reading course, or other special arrangement agreed upon between the students and faculty members concerned.

GEOLOGICAL SCIENCES

(Geology, Geochemistry, Geophysics, Geobiology, Physical Geography, Applied Fields)

Faculty: Arthur L. Bloom, L. L. Y. Chang, Kenneth F. Clark, W. Storrs Cole, George A. Kiersch, Wesley E. LeMasurier, Shailer S. Philbrick, John W. Wells.

Visiting Professor: Edwin D. McKee, United States Geological Survey, Denver, Colorado. (Fall term, 1968.)

Field Representative: George A. Kiersch, 140 McGraw Hall.

MAJOR SUBJECTS

Areal Geology
Engineering Geology
Geohydrology and Hydrogeology
Geomorphology
Geochemistry, Mineralogy-Petrology
Geobiology, Paleontology, and Stratigraphy
Mineral Deposits, Mining Geology
Physical Geography
Structural Geology and Geomechanics

MINOR SUBJECTS

All of the major subjects in the Field of Geological Sciences can also be taken as minor subjects, along with others in the department such as sedimentation, Pleistocene geology, water resources, and geological oceanography. Minor subjects outside of the Field of Geological Sciences may be chosen from many fields, such as agronomy, botany, engineering, chemistry, mathematics, physics, water resources, zoology, and biological sciences, or nonscientific fields.

The program of graduate study in the Field of Geological Sciences is designed to give broad training in the field and laboratory. Candidates for advanced degrees normally will take one or both minor subjects outside of the Field of Geological Sciences.

Graduate work in Geological Sciences may include investigation under approved direction in localities away from Ithaca and the northeastern states. A brochure about graduate work in Geological Sciences may be obtained by writing to the Field Representative.

ADMISSION REQUIREMENTS. Candidates with a major in this Field will be expected to offer for admission an A.B. degree or its equivalent. Students with undergraduate majors other than geology such as physical sciences or engineering may be admitted, with the expectation that deficiencies equivalent with the undergraduate major in Geological Sciences similar to those at Cornell University will be rectified soon after admission.

Applicants for graduate study in Geological Sciences should take the Graduate Record Examination Aptitude Test and Advanced Test in Geology in sufficient time to permit inclusion of the results in the application for admission to the Graduate School.

LANGUAGE REQUIREMENTS. *Master's:* proficiency in one of the following: French, German, or Russian, to be established before the completion of the second residence unit. *Doctorate:* proficiency in two of the following: French, German, Russian. Both must be established before the candidate will be allowed to schedule the Final Examination on his thesis.

Language examinations will be administered by the Graduate Language Board.

EXAMINATIONS. The Special Committee conducts all examinations required for the degree. At the time of entrance to the Field, a general examination covering the candidate's preparatory training may be given by the faculty to assist in planning a program of study.

For the Master's Degree: Final examination which consists of a comprehensive on the major and minor fields and the thesis. *For the Doctoral Degree:* a qualifying examination is required in addition to the examinations required by the Graduate School. The qualifying examination will determine the applicant's fitness for undertaking advanced studies and will enable the Special Committee to plan a program which will make the student familiar with the requisite knowledge in his chosen area. It must be taken before the end of the second semester in residence. The Graduate School requires a comprehensive Admission to Candidacy Examination and a Final Examination covering the thesis.

DEGREE REQUIREMENTS. *Master's degree:* a minimum of two residence units; proficiency in one language; submission of thesis and final examination. *Ph.D. Degree:* a minimum of six residence units; proficiency in two languages; a comprehensive Admission to Candidacy Examination on major and minor subjects; submission of dissertation and defense.

MASTER OF ARTS IN TEACHING. A Master of Arts in Teaching (Earth Science) program is offered in conjunction with the Department of Science Education; no thesis is required.

Research and Study Opportunities

The Ithaca region is particularly suited for research in stratigraphy, paleontology, geomorphology, and glacial geology. The nearby Adirondack area is a classic one for studies in metamorphic and igneous petrology. Research projects in structural geology, geomechanics, engineering geology, and hydrogeology are available at field sites in western as well as northeastern states, as are projects in mineral deposits, physical geography, and areal geology. The laboratories of the department contain standard as well as specialized equipment. Through the cooperating faculty of other departments on campus, every type of special and advanced equipment is available. The well-equipped laboratories and the exceptional libraries provide excellent opportunities for graduate research.

The department owns outstanding reference collections for teaching and research, such as: The Benjamin Silliman Jr. Collection of minerals acquired in 1868; suites of ores and host rocks from worldwide mining districts; and extensive invertebrate fossils of Paleozoic, Mesozoic, and Cenozoic from throughout the world; as well as the major collection of Recent mollusks (10,000 species) assembled by Wesley Newcomb and purchased in 1868 by Ezra Cornell.

The Paleontological Research Institution, a private research organization, is near the campus and its facilities are available to the specialized investigator.

The department has a cooperating agreement with the Museum of Northern Arizona, Flagstaff, for accommodating research projects and investigators. Every conceivable geologic condition and feature is available for study in the region, which constitutes an unusual field setting. The Committee for Labrador Studies has been pursuing research in Labrador for forty years, and projects are in progress on field mapping, glacial geology, and petrography.

For summer research grants in geological science at the Museum of Northern Arizona and elsewhere (after one year at Cornell), consult the Field Representative.

Interdisciplinary Studies

Graduate studies may be pursued in many of the specialized interdisciplinary areas of geological sciences as either a major or a minor at the Master's and doctorate levels, such as:

OCEANOGRAPHY. Oceanography and marine ecology are available through the Department of Conservation and the Division of Biological Sciences. Research projects are in progress in the Long Island coastal areas, and cooperative research with the Woods Hole Oceanographic Institute and Adelphi University is provided.

WATER RESOURCES. Water resources is available through the University-wide Water Resources Center with programs of study to meet individual requirements in the physical, biological, and social sciences, and in engineering.

A professional scientific hydrology program is available for majors in geohydrology in the Geological Sciences.

APPLIED BRANCHES. Programs of study are available in the following branches of applied geological science: mining geology-mineral deposits, petroleum geology, hydrogeology and geohydrology, and engineering geology. The major in a branch of applied geological science has two minors outside the department, in such subjects as soil science, hydraulics, water resources, soil mechanics, materials engineering, mathematics, chemistry, physics, economics, and regional planning.

COOPERATING FACULTY. Many additional interdisciplinary courses are offered by faculty in other departments or divisions such as: paleobotany, ecology-systematics, biogeochemistry, limnology, soil genesis, soil mineralogy, aerial photo analysis, regional planning, hydraulics and hydrology, and materials science and engineering.

Financial Aid

There are nine graduate teaching fellowships available in the Field of Geological Sciences. Appointments are for the academic year to supervise laboratory sections and other duties for approximately fifteen hours per week. The stipend ranges from $2200 to $2500, plus scholarships covering tuition and fees ($2050) for a total value of $4250 to $4550. Full residence credit is given for advanced degrees.

In addition, teaching fellows who are doctoral candidates are eligible for special summer awards of up to $500 to pursue their research projects.

The Eleanor Tatum Long Fellowship, restricted to research in the subject of structural geology and geomechanics, for either Master's or doctoral candidates, carries a stipend of $2100 and a scholarship covering tuition and fees ($2050) for a total value of $4150.

The department has several special endowments which, at the discretion of the staff, may be used to assist graduate students in their research and field work.

Research assistantships are available in certain cases from individual faculty research grants or contracts, either during the summer or the academic year.

The Graduate School administers a number of scholarships and fellowships. Awards are based on scholastic ability and promise of achievement as a graduate student. Besides the Cornell-supported awards, financial aid is offered by foundations and national agencies, e.g., NSF, NDEA, NASA, NIH, and by the State of New York.

Courses

(Students should check this tentative listing with department for any changes).

GEOGRAPHY, PHYSICAL

[312. GEOGRAPHY OF ANGLO-AMERICA]

Spring term. Credit four hours. Prerequisite: Geography 111 or Geology 102. Lectures, M W F 9:05 and additional assigned problems, Staff. Alternate-year course. Not offered in 1968–69.

The geographic provinces of Anglo-America, their geomorphic expression, climates, resources, development, and interrelationships.

314. CONTINENTAL GEOGRAPHY

Spring term. Credit four hours. Prerequisite: Geography 111 or Geology 102. Lectures, M W F 9:05 and additional assigned problems. Staff. Alternate-year course. Offered in 1968–69.

Physical geography, regional climatology, land use, and natural resources of a selected continent or region.

610. SPECIAL WORK

Throughout the year. Credit two hours a term. Prerequisite: consent of the instructor. Staff.

Special or original investigations in physical geography on the graduate level.

GENERAL GEOLOGY

Physical Processes

322. STRUCTURAL GEOLOGY

Spring term. Credit four hours. Prerequisites: Geology 102 (or 203) and 351; 352 recommended. Lectures, M W 11:15. Laboratory, M 2–4:25, and additional assigned problems. Field trips. Mr. Kiersch.

Nature, origin, and recognition of geologic structures. Behavior of geologic materials, stresses, geomechanical and tectonic principles applied to the solution of geologic problems. Analysis of structural features by three-dimensional methods.

[421. SEDIMENTATION]

Fall term. Credit four hours. Prerequisite: Geology 352; Geology 441 recommended. Lectures, M W 9:05. Laboratory, T 2–4:25, and additional laboratory work. Field trips. Messrs. Philbrick and Kiersch. Alternate-year course. Not offered in 1968–69.

Source materials, mechanics of transport and dispersal, depositional environments, lithification and diagenesis of sediments. Analysis of common problems in applied fields due to these phenomena.

441. GEOMORPHOLOGY

Fall term. Credit four hours. Prerequisite: Geology 102. Lectures, T Th 9:05. Laboratory, T 2–4:25, and additional assigned problems. Mr. Bloom.

Description and interpretation of land forms in terms of structure, process, and stage.

444. GEOLOGICAL OCEANOGRAPHY

Spring term. Credit three hours. Prerequisite: Geology 102 or Biological Sciences 461. Lectures, M W F 9:05. Field trips. Mr. Bloom.

Shoreline erosion, transportation and deposition; origin and structure of continental shelves and ocean basins. Geologic processes and geomorphic development in the marine environment.

522. FLUVIAL PROCESSES (or Civil Engr. 2333)

Spring term. Credit two hours. Prerequisite: consent of the instructors. Seminar, hours to be arranged. Field trips. Course offered jointly with the School of Civil Engineering on demand. Messrs. Graf and Kiersch.

The common problems of fluvial processes, hydraulics, and sediment transport are studied along with the appropriate analytical methods and experimental techniques.

542. GLACIAL AND PLEISTOCENE GEOLOGY

Spring term. Credit three hours. Prerequisite: Geology 441 or consent of the instructor. Lectures, T Th 9:05. Laboratory, T 2–4:25. Several Saturday field trips. Mr. Bloom.

Glacial processes and deposits and the stratigraphy of the Pleistocene.

GEOCHEMISTRY

Mineral Materials and Processes

351. MINERALOGY

Fall term. Credit four hours. Prerequisites: Geology 102 and Chemistry 108. Lectures, M 10:10. Laboratory, W F 2–4:25. Mr. Chang.

Crystallography, chemical and physical properties, occurrence, uses and identification of rock-forming minerals.

352. PETROLOGY

Spring term. Credit four hours. Prerequisite: Geology 351. Lectures, M F 10:10. Laboratory, T 2–4:25; additional assigned problems. Mr. LeMasurier.

Composition, classification, and origin of igneous, sedimentary, and metamorphic rocks.

451. OPTICAL MINERALOGY

Fall term. Credit four hours. Prerequisite: Geology 351. Lecture, T 11:15. Laboratory, T W 2–4:25 and additional assigned problems. Mr. LeMasurier.

Optical properties of crystals and their application to the determination and study of common rock-forming minerals with the petrographic microscope.

452. OPTICAL PETROGRAPHY

Spring term. Credit four hours. Prerequisites: Geology 352 and 451. Lecture, T 11:15. Laboratory, T W 2–4:25, and additional assigned problems. Mr. LeMasurier.

Description, classification, and determination of the origin of igneous, metamorphic, and sedimentary rocks by the use of the petrographic microscope.

551. GEOCHEMISTRY

Fall term. Credit three hours. Prerequisite: Geology 352. Lectures M W F 8. Mr. Chang.

Heterogeneous equilibria and reactions at high temperatures and pressures among rock-forming minerals; includes chemistry of weathering.

554. X RAY ANALYSIS

Spring term. Credit two hours. Prerequisite: Geology 352 or consent of the instructor. Lecture, W 12:20. Laboratory, F 2–4:25. Mr. Chang. Alternate-year course. Offered in 1968–69.

Theory and use of x ray diffraction and spectroscopy in identification and analysis of minerals, rocks, and soils.

653. ADVANCED PETROLOGY

Fall term. Credit three hours. Prerequisite: Geology 452. Lectures, T Th 9:05. Laboratory, Th 2–4:25. Mr. LeMasurier.

Methods of study, geologic and geochemical relationships, and petrogenesis of igneous and metamorphic rocks.

656. ADVANCED MINERALOGY

Spring term. Credit three hours. Prerequisites: Geology 452 and 554. Lectures, T Th 9:05. Laboratory, Th 2–4:25. Mr. Chang.

A theoretical treatment of the crystal chemistry and thermodynamics of rock-forming minerals.

Mineral Deposits

461. MINERAL DEPOSITS: METALS

Fall term. Credit four hours. Prerequisite: Geology 352. Lectures, M W F 10:10. Laboratory, F 2–4:25. Field trips. Mr. Clark.

Principles and processes involved in the formation of mineral deposits. Modes of occurrence, origin, distribution, and utilization of the major, rare, and minor metals.

462. MINERAL DEPOSITS: NONMETALS

Spring term. Credit four hours. Prerequisite: Geology 461 or consent of the instructor. Lectures, M W F 10:10. Laboratory, F 2–4:25. Field trips. Mr. Clark.

Properties, occurrence, associations, distribution, and economic utilization of the industrial minerals and rocks.

[563. ORE MICROSCOPY]

Fall term. Credit two hours. Prerequisites: Geology 451 and 461. Laboratory, F S 7:30–9:55 A.M. Alternate-year course. Not offered in 1968–69. Mr. Clark.

Identification of ore-minerals in polished sections which reflect light by etching and microchemical reactions; study and interpretation of mineral relationships.

GEOPHYSICS

581. EXPLORATION GEOPHYSICS

Fall term. Credit three hours. Prerequisites: Physics 208, Geology 102 or 203; Geology 322 is recommended. Lectures, T Th 9:05. Laboratory, S 10:10–12:35, and assigned problems. Mr. Clark. Alternate-year course.

Elementary theory and interpretation of data from exploration geophysical methods. Environmental geology and selection of techniques for important applied areas.

APPLIED GEOLOGICAL SCIENCE

[532. HYDROGEOLOGY]

Spring term. Credit three hours. Prerequisites: Geology 322, 352; Geology 441 is recommended. Lectures, M W 9:05. Laboratory, T 2–4:25 and field trips. Mr. Philbrick. Alternate-year course. Not offered in 1968–69.

Hydrologic cycle and water provinces; occurrence, movement, quantity, and chemical quality of ground water in porous media. Water resources development.

533. ENGINEERING GEOLOGY – THEORY AND ENVIRONMENTS

Fall term. Credit three hours. Prerequisites: Geology 322, 352; Geology 441 is recommended. Lectures, M W 11:15. Laboratory, M 2–4:25 and field trips. Mr. Kiersch.

Advanced study of the physical phenomena and rock properties of special importance from the planning through the operation stages of engineering works; includes underground fluids, subsidence, gravity movement, seismicity, geomechanics and stresses, weathering, and geologic materials of construction. Analysis of geologic problems encountered in practice; predicting the influence of natural and man-made environmental factors.

535. ENGINEERING GEOLOGY – PRACTICE

Fall term. Credit three hours. Prerequisites: Geology 533 or 322–352 and 441. Lectures, M W 9:05. Laboratory, T 2–4:25 and field trips. Mr. Philbrick. Alternate-year course.

Application of geological principles in the planning-design, construction, and operation of engineering works. Case histories, analysis, and evaluation of physical environmental factors, remedial treatment, and reports.

[561. FUNDAMENTALS OF MINING GEOLOGY]

Fall term. Credit three hours. Prerequisites: Geology 461 and 462. Lectures, M W F 10:10. Assigned problems. Field trips. Mr. Clark. Alternate-year course. Not offered in 1968–69.

Principles of geological, geophysical, and geochemical techniques used in mineral exploration. Mining geology, guides to ore, mining methods.

[562. ECONOMICS OF MINERAL DEPOSITS]

Spring term. Credit three hours. Prerequisites: Geology 461 and 462; Geology 561 is recommended. M W F 10:10. Assigned problems. Mr. Clark. Alternate-year course. Not offered in 1968–69.

Sampling and ore estimation. Cutoff, grade, tonnage, and economic factors related to mining and mineral marketing. Financial calculations and procedures used in mineral property valuation.

582. EXPLORATION GEOLOGY

Spring term. Credit three hours. Recommended for all graduate students in geological sciences. Prerequisites: graduate standing and field geology. Lectures, M W 9:05. Laboratory, W 2–4:25. Messrs. Philbrick and Kiersch. Alternate-year course.

Methods of exploration and appraisal of geologic data from both field and laboratory investigations. Assessment of environmental geology and the presentation of direct and indirect information for professional purposes and applied fields.

GEOBIOLOGY

Paleontology and Stratigraphy

471. INVERTEBRATE PALEONTOLOGY

Fall term. Credit four hours. Prerequisites: Geology 102, and, if possible, invertebrate zoology. For those interested in fossil evidence of the development of organisms. Lectures, T Th 10:10. Laboratory, W Th 2–4:25. Mr. Cole.

Paleobiology and classification of important fossil invertebrates.

472. PRINCIPLES OF HISTORIC GEOLOGY

Spring term. Credit four hours. Prerequisites: Geology 322 and 471. Lectures, T Th 10:10. Laboratory, W 2–4:25, and additional assigned problems. Mr. Wells.

Application of geologic principles to interpretation of earth history; development of the geologic column, geochronology and geochronometry; correlation and the zone concept; sedimentary environments and provinces; geosynclines and platforms; problems of the pre-Cambrian and continental evolution.

571. STRATIGRAPHY: PALEOZOIC

Fall term. Credit three hours. Prerequisite: Geology 472. Lectures, T Th 9:05 and W 7:30 P.M. Mr. Wells. Alternate-year course.

Principles of stratigraphy developed by detailed study of selected American and European systemic examples.

572. STRATIGRAPHY: MESOZOIC AND CENOZOIC

Spring term. Credit three hours. Prerequisite: Geology 472. Lectures, T W Th 9:05 Messrs. Cole and Wells.

Principles of stratigraphy developed by detailed study of selected American and European systemic examples.

671. MICROPALEONTOLOGY

Spring term. Credit two hours. Prerequisites: Geology 472 and 572. Lecture, W 9:05. Laboratory, W 2–4:25, and additional assigned problems. Mr. Cole.

Microfossils, chiefly Foraminifera.

[672. STRATIGRAPHY OF NEW YORK STATE]

Spring term. Credit three hours. Prerequisite: Geology 571. Lectures, T Th 12:20 early in the term, followed by all-day and weekend field trips. Mr. Wells. Alternate-year course. Not offered in 1968–69.

The classic Paleozoic sections of New York studied through lectures, readings, and field observation.

SEMINARS AND SPECIAL WORK

GEOLOGY 673. SEMINAR IN THE HISTORY OF GEOLOGY

Fall term. Credit two hours. Hours to be arranged. Mr. Wells.

Part of the graduate program in the history of science.

SEMINAR IN GEOLOGICAL SCIENCES

Each term. No credit. For majors and required of graduate students, but open to all who are interested. T 4:45. Staff and visiting lecturers.

Reports and discussion of current research in the geological sciences.

690. SPECIAL WORK

Throughout the year. Credit two hours a term. Prerequisite: consent of the instructor. Staff.

Advanced work on original investigations in geological sciences on the graduate level.

690-a. Petrological and mineralogical chemistry: Mr. Chang

690-b. Volcanic petrology and geochemistry: Mr. LeMasurier

690-c. Coastal geomorphology and Pleistocene geology: Mr. Bloom

690-d. Engineering geology, geomechanics, and hydrogeology: Mr. Kiersch

690-e. Invertebrate paleontology and geomorphology: Mr. Cole

690-f. Invertebrate paleontology and paleoecology: Mr. Wells

690-g. Sedimentology and primary structures

A special lecture seminar by Mr. E. D. McKee, fall term. Credit one hour. Hours to be arranged.

690-h. Physical and engineering geology, water resources: Mr. Philbrick

690-i. Mineral deposits and resources, geophysics: Mr. Clark

MATERIALS SCIENCE AND ENGINEERING

Faculty: Robert W. Balluffi, Boris W. Batterman, John M. Blakely, Malcolm S. Burton, John P. Howe, Joseph O. Jeffrey, Herbert H. Johnson, Edward J. Kramer, Che-Yu Li, Walter S. Owen, Thor N. Rhodin, Arthur L. Ruoff, Henri S. Sack, Stephen L. Sass, Eraldus Scala, David Seidman, Benjamin M. Siegel, John Silcox, Floyd O. Slate, George V. Smith, Anthony Taylor, Watt W. Webb.

Field Representative: Che-Yu Li, 329 Bard Hall.

MAJOR SUBJECTS	MINOR SUBJECTS
Materials Science	Materials Science
Materials and Metallurgical Engineering	Materials and Metallurgical Engineering

ADMISSIONS REQUIREMENTS. Graduates from any undergraduate engineering or physical science program will be accepted if they have demonstrated marked competence in the basic parts of their studies and show competence, in general, as graduate students. Applicants who lack some prerequisites for graduate courses recommended by the Field, but are otherwise

qualified, will be allowed to remedy the deficiency by taking undergraduate courses while enrolled as graduate students.

It is recommended, but not required, that applicants present the results of the Graduate Record Examination with their applications.

LANGUAGE REQUIREMENTS. There are no language requirements for the M.S. or Ph.D. degrees.

EXAMINATIONS. All examinations required for a degree are administered and reported by the candidate's Special Committee. The examinations may be oral, or written and oral. In accord with Graduate School legislation, a comprehensive examination is required for admission to Ph.D. candidacy. A thesis examination is given upon submission of the Ph.D. thesis.

For the M.S. degree, an examination is required at the time of submission of the M.S. thesis. At the discretion of the Special Committee, this examination may consider the thesis, or the thesis and course work. Under suitable circumstances, the Master's final examination and the Admission to Candidacy Examination may be combined.

Research and Study Opportunities

Graduate programs in Materials Science and Engineering lead to careers either in research and development, or in engineering application of materials. This is accomplished through comprehensive and integrated course programs, participation in formal and informal research seminars, thesis research, and not infrequently in hallway discussions.

The spectrum of current research programs in the Field is very broad, ranging from problems of immediate technological interest such as crack propagation in high strength steels to considerably more basic investigations in such areas as point defects and superconductivity.

Current research in the Field includes the following:

1. Mechanical behavior: interstitial and substitutional solid solutions, crack formation and propagation, embrittlement phenomena, fatigue, composite materials, anelasticity.
2. Imperfections in solids: point defects, dislocation mechanics, defect interactions, radiation damage, substructure.
3. Phase transformations: crystal growth, precipitation, martensite, alloy steels, superconductivity, solidification, phase decomposition during sintering.
4. Surface structure and reactions: solid-liquid and solid-gas interfaces, field ion microscopy, surface diffusion, low energy electron diffraction, crystal nucleation.
5. High temperature materials: structure and properties of pyrolytic graphite, composite materials, refractory metals and alloys, complex compounds, sintering of ceramics.
6. High pressure studies: creep, diffusion, elastic constants, electrical properties.
7. Electrical and magnetic behavior: superconductivity, semiconductors, NMR, conduction in oxides, magnetic domain wall motion, photoconductivity.
8. Development of advanced experimental techniques: electron microscopy, x ray, high pressure, crystal growing, purification methods.

More detailed information about course programs and research areas is available upon request.

A strong catalyst for the materials research activities at Cornell has been provided by the Materials Science Center, which is supported by the Advanced

Research Projects Agency of the U.S. Government, and with which most of the Field faculty are affiliated. The MSC provides substantial financial assistance for graduate students through research assistantships, new equipment for approved thesis research projects, and in some cases, technician assistance in performing routine measurements.

A most important contribution of MSC has been the creation and maintenance of central research facilities which are used by both faculty and graduate students. Each central facility is directed by a senior staff member and staffed by trained technicians. Faculty and students receive expert guidance and assistance from these facilities, which include laboratories for materials preparation, metallography, x ray diffraction, electron microscopy, electronics, high pressure, low temperature, chemical analysis, irradiation and nonmetallic crystal growth.

Professional Degree

In addition to the M.S. and Ph.D. programs, the Field also offers the professional degree of Master of Engineering (Materials). The professional program, available to students who have demonstrated suitable proficiency in the areas of materials and metallurgy in earning their Bachelor's degree, provides advanced courses designed to enlarge the student's preparation for a career in professional engineering with less emphasis on achievement in research. The Master of Engineering program is administered by the Engineering Division of the Graduate School (See pages 177–178).

Courses

GRADUATE CORE PROGRAM: MATERIALS SCIENCE AND ENGINEERING

6601. TOPICS IN THERMODYNAMICS AND KINETICS

Credit three hrs. Fall.

Generalization of thermodynamics to include nonchemical forms of energy. Statistical nature of entropy. Phase stability. Defect equilibria. Thermodynamics of solutions, surfaces, and interfaces. Reaction kinetics. Diffusion. At the level of Slater, *Introduction to Chemical Physics;* Guggenheim, *Thermodynamics.*

6602. PHASE TRANSFORMATIONS

Credit three hrs. Spring.

Spinodal decomposition. Nucleation theory. Diffusional growth. Formal theory of nucleation and growth transformations. Diffusionless transformations. Applications of the theory to specific changes in real materials. At the level of Christian, *Phase Transformation.*

6603. CRYSTAL MECHANICS

Credit three hrs. Fall.

Crystal symmetry. Vector fields and tensor fields. Lattice deformation and fault crystallography. Reversible tensor properties of crystals. Relationships between different tensor properties. Crystal elasticity, elastic waves and polymer elasticity. Lattice dynamics. Thermophysical properties. Irreversible tensor properties. Coupling of transport phenomena. Higher order effects. At the level

of Nye, *Physical Properties of Crystals;* Born and Huang, *Dynamical Theory of Crystal Lattices;* and Smith, *Wave Mechanics of Crystalline Solids.*

6604. DISLOCATIONS

Credit three hrs. Fall.

Review of elementary geometrical and strain energy aspects of dislocation theory. Experimental evidence for dislocations. Dislocation elasticity. Energy consideration. Applied stresses. Point defects. Crystallographic aspects of dislocation theory, stacking faults, partials, Thompson tetrahedron and layer structures. Jogs. Strain hardening in single crystals. Mechanical twinning. At the level of Friedel, *Dislocations.*

6605. ELECTRICAL AND MAGNETIC PROPERTIES OF ENGINEERING MATERIALS

Credit three hrs. Fall. Prerequisite: Physics 454 or consent of the instructor.

Electrical properties of semiconductors. Metallic alloys. Ferromagnetic materials. Superconductivity. Optical and dielectric properties of insulators and semiconductors. Ferrites. At the level of Kittel, *Introduction to Solid State Physics;* Chikazumi, *Physics of Magnetism;* Lynton, *Superconductivity;* Livington and Schadler, *The Effect of Metallurgical Variables on Superconductivity Properties.*

6606. MECHANICAL BEHAVIOR OF MATERIALS

Credit three hrs. Spring.

Geometry of slip in single crystals. Strain hardening and recovery. Dislocation dynamical treatment of yield and flow. Interaction of interstitial solute atoms with dislocation. Solution hardening. Two-phase hardening. Time dependent deformation. Ductile and cleavage, fracture, fatigue, creep-rupture, and stress-corrosion fracture. At the level of review articles in *Progress in Materials Science* and various conference reports.

6611. PRINCIPLES OF DIFFRACTION

Credit three hrs. Fall. Offered jointly with Applied Physics (8211).

General principles applied to diffraction of electrons, neutrons and x rays. Production of neutrons, x rays, their absorption and scattering. Compton effect. Diffraction from periodic lattices. Crystal symmetry. Single crystal and powder techniques. Fourier methods. Thermal vibrations and thermal scattering. Diffraction from gases and liquids. Introduction to dynamical diffraction of rays and electrons. Extinction phenomena and perfect crystals. Selected experiments in diffraction.

For the Professional Master's Degree

6503. MATERIALS SELECTION AND USE

Credit three hrs. Fall. Three lectures. Prerequisite: 6432. Mr. Smith.

Metallurgical and mechanical factors governing the selection of metals for various services. Analysis of service requirements and the selection and fabrication of metals to fulfill such requirements; analysis of service failures of metals and remedies for such failures; and study of the merits and limitations of materials applications in existing products and equipment.

6553–6554. PROJECT

Credit three hrs. Fall, spring.

Research on a specific problem in materials or metallurgical engineering.

6555. MATERIALS PROCESSING

Credit three hrs. Spring. Three lectures.

A course on the principles of materials processing including both metallic and nonmetallic materials. The control of materials properties and various solutions to engineering problems of shaping, making, and treating practice are stressed.

Other Graduate Courses

6612. SELECTED TOPICS IN DIFFRACTION

Credit three hrs. Spring. Three lectures. Prerequisite: 6611. Offered jointly with Applied Physics (8212).

Dynamical diffraction: Ewald-von Laue theory of dynamical diffraction applied to x rays and electrons. Currently developing theory and application to defects in solids. Phenomena investigated via diffuse scattering: phonons, measurement of dispersion curves, frequency spectrum, Debye temperatures, vibrational amplitudes. Order-disorder phenomena, short and long-range order, Guinier-Preston zones. Selected topics of current interest related to x ray, neutron, and electron diffraction, with contributions from several members of the faculty.

6762. PHYSICS OF SOLID SURFACES

Credit three hrs. Three lectures. Offered jointly with Applied Physics (8262). Spring.

Physical principles describing the behavior of atoms, ions, and electrons at surfaces or in two dimensional structures. Emphasis on applications to phenomena or matter in which the role of surfaces and interfaces is important. Equilibrium thermodynamics and statistical mechanics of interfaces. Atomistic theory of surface forces, surface energy and surface structure. Kinetics of heterogeneous processes including evaporation, condensation, adsorption, and chemical reaction. Capillary effects and mechanisms of interfacial phenomena in materials. Presented at the level of review articles such as *Progress in Materials Science* and *Solid State Physics* series.

6872. NUCLEAR MATERIALS

Credit three hrs. Spring. Three lectures. Prerequisites: Materials Science, Physical Chemistry, or equivalent and consent of the instructor. Mr. Howe.

Application of materials science to choice and design of systems used in nuclear reactors. Emphasizes effects of radiation, temperature, temperature differences, composition, and structure. Brings in preparation, fabrication, and use of reactor materials and components.

MATHEMATICS

Faculty: Ralph P. Agnew, James B. Ax, Michael S. Balch, Israel Berstein, Lawrence D. Brown, Jan M. Chaiken, Stephen U. Chase, Clifford J. Earle, James Eells, Jr., William G. Faris, Roger H. Farrell, Wolfgang H. J. Fuchs, Solomon Garfunken, Hillel H. Gershenson, Leonard Gross, Richard S. Hamilton, David W. Henderson, Carl S. Herz, Peter J. Hilton, Peter J. Kahn, Harry Kesten, Jack Kiefer, Anthony W. Knapp, Richard B. Lavine, Simon A. Levin, Stephen Lichtenbaum, G. Roger Livesay, Michael D. Morley, Anil Nerode, Paul Olum, Lawrence E. Payne, Richard A. Platek, George S. Rine-

hart, Alex Rosenberg, Oscar S. Rothaus, Duane P. Sather, Stephen H. Schanuel, Alfred H. Schatz, Leonard S. Silver, Frank L. Spitzer, Moss E. Sweedler, Robert J. Walker, Hsien-Chung Wang, Harold Widom, Jacob Wolfowitz.

Field Representative: Alex Rosenberg, 124 White Hall.

MAJOR AND MINOR SUBJECTS

Algebra	Geometry
Analysis	Mathematics

Prerequisites for admission are a knowledge of advanced calculus (including both theoretical and applied points of view) and modern algebra.

The Field of Mathematics has set the following language requirements: none for the Master's degree, a reading knowledge of German *or* Russian for the Ph.D. degree. There is no formal French requirement, but books and papers in that language will be freely used in all graduate courses and students can expect to be called upon to read French mathematical texts.

The Field of Mathematics requires teaching experience of all graduate students as part of the requirements for an academic degree.

Candidates for the Master's degree are expected to obtain some understanding of mathematical thought, ordinarily by taking about twenty-four hours of courses at the graduate level. Qualifications for the Doctor's degree include a broad acquaintance with the basic subjects of present-day mathematics plus a demonstration of ability to do research in one or more branches of mathematics.

A booklet entitled *Graduate Work in Mathematics at Cornell* may be obtained by writing to the Chairman, Department of Mathematics, White Hall. The booklet contains additional information about graduate work, thesis and examination requirements, and research in mathematics for the entering graduate student.

All the three major subdivisions of mathematics, algebra, analysis, and geometry are well represented at Cornell. Moreover, the department is also very strong in logic, probability, and statistics. A detailed listing of the research interests of the members of the faculty will be sent to all who request the booklet *Graduate Work in Mathematics* referred to above.

Courses

In all 600-level courses, as well as in Courses 502, 553, and 554, the final grades will be only S or U.

All listings are tentative; students should check with the departmental office for definite listings, times, places, etc.

The advanced courses, 500 and 600 level, shown below are the ones offered during 1967–68. In 1968–69 about the same number of advanced courses will be given; they will be selected from those offered in 1967–68 and the bracketed courses which are not being offered in 1967–68.

GENERAL

502. GRADUATE PROSEMINAR

Spring term. Credit four hours. Prerequisite: candidacy for an advanced degree with a major in mathematics. M W F 4. Messrs. Eells and Ganelius.

Presentation by students of material in mathematical literature. Required of all graduate students majoring in mathematics.

APPLIED MATHEMATICS AND DIFFERENTIAL EQUATIONS

315. HIGHER CALCULUS

Fall term. Credit three hours a term. Prerequisite: 213 or 293. T Th S 10:10. Mr. Lavine.

Intended for students who have had only three semesters of calculus. It does not prepare a student for 415-416, and will not meet the needs of those graduate students whose work requires really serious application of mathematical methods.

Vector calculus, ordinary and partial differential equations, special functions, Fourier series, Laplace and Fourier transforms, complex variables. The material in the old 315–316 is covered in the revised 315 plus the linear algebra course, 331.

415–416. MATHEMATICAL METHODS IN PHYSICS

Throughout the year. Credit four hours a term. Undergraduates will be admitted only with the consent of the instructor. First term prerequisite to second. T W Th 12:20. Mr. Fuchs.

Intended for graduate students in physics or related fields who have had a strong advanced calculus course and at least two years of general physics. The course goes very quickly, covering in two semesters slightly more than 421–422–423.

Lectures and problem work designed to give a working knowledge of the principal mathematical methods used in advanced physics. Topics include infinite series, Fourier series and integrals, Laplace transforms, complex variable, calculus of variations, matrices, integral equations, and eigenvalue problems.

421. APPLICABLE MATHEMATICS

Fall term. Credit four hours. Prerequisite: 222, or honors section of 294, or consent of the instructor. (Students from regular sections of 294 will be admitted upon the 294 instructor's recommendation, provided their grades are very high and they make up the extra work.) M W F 12:20, Th 2:30.

Graduate students who need mathematics extensively in their work and who have had a solid advanced calculus course as undergraduates should take 415–416. If they have not had such an advanced calculus course they should take 421–422–423. If their preparation is still too weak for this, they should take all or part of 221–222, followed by 421–422–423.

Theorems of Stokes, Green, Gauss, etc. Sequences and infinite series. Fourier series and orthogonal functions. Introduction to complex variables.

422. APPLICABLE MATHEMATICS

Spring term. Credit four hours. Prerequisite: 421 or consent of the instructor. M W F 12:20, Th 2:30. Mr. Rothaus.

Continuation of complex variables. Conformal mappings. Harmonic functions. Some special functions. Differential equations. Laplace and Fourier transforms. Asymptotic expansions of functions.

423. APPLICABLE MATHEMATICS

Fall term. Credit four hours. Prerequisite: 422. M W F 12:20, Th 2:30. Mr. Spitzer.

Linear operators and integral equations. Calculus of variations. Application to eigenvalue problems. Green's function, and treatment of special problems of mathematical physics.

427–428. INTRODUCTION TO DIFFERENTIAL EQUATIONS

Throughout the year. Credit four hours a term. Prerequisite: 222, or 294, or consent of the instructor. First term prerequisite to second. M W F 12:20. Mr. Hager.

First term, ordinary differential equations covering the basic theory. Topics include uniqueness and existence theory, Sturm-Liouville theory, singular points, stability, approximation methods and applications. Second term, partial differential equations with treatments of Laplace, heat and wave equations. Topics include classification, maximum principles, uniqueness, stability, approximation methods and applications.

517–518. ORDINARY DIFFERENTIAL EQUATIONS

Throughout the year. Credit four hours a term. Prerequisites: 411–412 and concurrent registration in 413. First term prerequisite to second. M W F 10:10. Mr. Levin.

Existence and uniqueness. Autonomous systems, with specialization to geometric theory in two dimensions. Linear equations. Stability. Bifurcation theory. Some special functions of mathematical physics, from the viewpoint of equations in the complex domain and the two point boundary value problem.

519–520. PARTIAL DIFFERENTIAL EQUATIONS

Throughout the year. Credit four hours a term. Prerequisite: concurrent registration in 413 or, with consent of the instructor, 423 or 416. First term prerequisite to second. T Th S 10:10. Mr. Balch.

Classification of partial differential equations. Questions of existence, uniqueness, and continuity of the solutions of typical boundary value problems. The equations of Laplace and Poisson, principle of the maximum and the mean; the wave equation, heat equation.

521. ELEMENTARY FUNCTIONAL ANALYSIS

Fall term. Credit four hours. Prerequisite: 415–416 or 421–422–423, or consent of the instructor. T Th S 9:05. Mr. Lavine.

Elementary set theory and topology, Banach and Hilbert spaces, measure and integration, spectral theorem for bounded operators. Graduate students in mathematics should take 613 for functional analysis.

522. APPLIED FUNCTIONAL ANALYSIS

Spring term. Credit four hours. Prerequisite: 521. T Th S 9:05. Mr. Lavine.

Spectral theory for unbounded operators in Hilbert space, compact operators, representations of compact groups, distributions. Applications to Fourier analysis, integral and differential equations, calculus of variations, quantum mechanics.

Note: Since the content of the 1968 version of 522 is quite different from that of the 1967 version, students could possibly take 522 twice with profit.

627–628. SEMINAR IN PARTIAL DIFFERENTIAL EQUATIONS

Throughout the year. Credit four hours. Prerequisite: consent of the instructor. Hours to be arranged. Mr. Payne.

[619–620. ADVANCED PARTIAL DIFFERENTIAL EQUATIONS.]

Not offered in 1967–68.

Throughout the year. Credit four hours. Prerequisite: 519–520.

ANALYSIS

411–412. INTRODUCTION TO ANALYSIS

Throughout the year. Credit four hours a term. Prerequisite: 222. T Th S 10:10. Messrs. Hamilton and Schneider. (There will be a special Honors section of this course. The instructor should be consulted.)

An introduction to the theory of functions of real variables, stressing rigorous logical development of the subject rather than technique of applications. Topics include elementary topology, the real number system, continuous and differentiable functions, integration, convergence and approximation theorems, Fourier series, calculus in several variables, elementary differential geometry.

413. INTRODUCTION TO THE THEORY OF FUNCTIONS OF ONE COMPLEX VARIABLE

Spring term. Credit four hours. Prerequisite: 222 or 312. M W F 9:05. Course 411 is not a prerequisite, but some previous acquaintance with advanced calculus as presented in 411 is definitely helpful. Mr. Knapp.

A rigorous introduction to complex variable theory. Intended mainly for undergraduates and for graduate students outside mathematics. Complex numbers. Differential and integral calculus for functions of a complex variable including Cauchy's theorem and the calculus of residues. Elements of conformal mapping. Elements of several complex variables.

511–512. REAL AND COMPLEX ANALYSIS

Throughout the year. Credit four hours a term. Prerequisite: 412. M W F 9:05. Mr. Ganelius.

First term: set-theoretic preliminaries, abstract integration. Borel measures, Lebesgue measures, L_p spaces, Hilbert spaces, Banach spaces, product spaces, differentiation. Second term: Fourier transforms. Complex variables, harmonic functions, Schwarz lemma, approximation by rational functions, conformal mappings, including Riemann mapping theorem, Weierstrass- and Mittag-Leffler theorems, Jensen's formula, analytic continuation, the modular function, Picard's theorem.

523. ANALYSIS ON MANIFOLDS

Spring term. Credit four hours. Prerequisites: 500 and 512. Hours to be arranged. Mr. Eells.

Calculus on Banach spaces and manifolds.

611–612. SEMINAR IN ANALYSIS

Throughout the year. Credit four hours. Prerequisite: consent of the instructor. Hours to be arranged. Fall term, Mr. Hamilton. Spring term, Mr. Earle.

613. FUNCTIONAL ANALYSIS

Spring term. Credit four hours. Prerequisites: 432 and 512. Hours to be arranged. Mr. Faris.

Topological vector spaces, Banach and Hilbert spaces, Banach algebras. Additional topics to be selected by instructor.

615. FOURIER ANALYSIS

Fall term. Credit four hours. Prerequisites: 500 and 512. Hours to be arranged. Mr. Herz.

L_p spaces of functions on Euclidean space. The Marcinkiewicz interpolation theorem. Fourier transforms of functions in L_p. The Hardy-Littlewood maximal theorem. Singular integrals.

617. ANALYTICAL NUMBER THEORY

Fall term. Credit four hours. Prerequisite: 514. Mr. Wirsing.

623. SEVERAL COMPLEX VARIABLES

Fall term. Credit four hours. Prerequisites: 500 and 514. Hours to be arranged. Mr. Rothaus.

Basic definitions, local properties, power series and plurisubharmonic functions, convexity and analytic envelopes.

[514. COMPLEX VARIABLE THEORY]

Spring term. Credit four hours. Prerequisites: 411 and 500. Not offered in 1967–68.

[528. VARIATIONAL METHODS]

Spring term. Credit four hours. Prerequisite: 413. Not offered in 1967–68.

[621. MEROMORPHIC FUNCTIONS]

Fall term. Credit four hours. Prerequisite: consent of the instructor. Not offered in 1967–68.

[622. RIEMANN SURFACES]

Spring term. Credit four hours. Prerequisites: 514, 531, 551. Not offered in 1967–68.

ALGEBRA

431–432. INTRODUCTION TO ALGEBRA

Throughout the year. Credit four hours a term. Prerequisite: 221 or 331. First term prerequisite to second. M W F 10:10. (There will be a special Honors section of this course. The instructor should be consulted.) Messrs. Beck and Lichtenbaum.

A rigorous introduction to modern algebra. First term: linear algebra. Second term: introduction to algebraic systems such as groups, rings, modules and fields.

531–532. ALGEBRA

Throughout the year. Credit four hours a term. Prerequisite: 432. First term prerequisite to second. T Th 2:30–4. Mr. Sweedler.

First term: finite groups, field extensions. Galois theory, rings and algebras, tensor algebra. Second term: Wedderburn structure theorem, Brauer group, group cohomology, Ext, Dedekind domain, primary decomposition, Hilbert basis theorem, local rings. Additional topics selected by instructor.

631–632. SEMINAR IN ALGEBRA

Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor. Hours to be arranged. Fall term, Mr. Froehlich. Spring term, Mr. Schanvel.

635. THEORY OF RINGS

Fall term. Credit four hours. Hours to be arranged. Mr. Silver.

Advanced topics in commutative Noetherian rings including some of the following: regular local rings; the Koszul complex; depth; multiplicity; Macaulay rings. Prerequisites are homological algebra and some familiarity with the basic notions of Noetherian rings.

639. HOPF ALGEBRAS

Spring term. Credit four hours. Prerequisite: 531. Mr. Sweedler.

641. CATEGORICAL ALGEBRA

Fall term. Credit four hours. Prerequisite: 531. Mr. Rinehart.

[549–550. LIE GROUPS]

Throughout the year. Credit four hours a term. Prerequisites: 500 and 531. Not offered in 1967–68.

[633. GROUP THEORY]

Spring term. Credit four hours. Prerequisite: 531. Not offered in 1967–68.

[637. ALGEBRAIC NUMBER THEORY]

Spring term. Credit four hours. Prerequisite: 531. Not offered in 1967–68.

GEOMETRY AND TOPOLOGY

451–452. CLASSICAL GEOMETRIES

Throughout the year. Credit four hours a term. Prerequisite: 221 or 331 or 431, which may be taken concurrently. First term prerequisite to second. T Th S 9:05. Mr. Berstein.

Axiomatic methods in geometry. Foundations of Euclidean geometry. Non-Euclidean geometry, projective geometry, other geometric theories.

454. INTRODUCTION TO DIFFERENTIAL GEOMETRY

Spring term. Credit four hours. Prerequisite: 222. M W F 11:15 Mr. Wang.

An introduction to differential forms and their application to the study of curves, surfaces, and higher dimensional manifolds.

500. GENERAL TOPOLOGY

Fall term. Credit four hours. Prerequisite: 412. M W F 3:35. Mr. Gershenson.

Topics from set theory, topological spaces, function spaces, fiber spaces, manifolds, and topological groups.

551. INTRODUCTORY ALGEBRAIC TOPOLOGY

Spring term. Credit four hours. Prerequisites: 432 and 500. M W F 3:35. Mr. Olum.

Homology and cohomology theories for complexes and spaces. Manifolds and geometric applications.

553–554. ALGEBRAIC TOPOLOGY

Throughout the year. Credit four hours a term. Prerequisite: 551 or the equivalent. Hours to be arranged. Mr. Moss.

Categories and functors, exact and half-exact functors, homotopy theory, cohomology operations, spectral sequences, and applications.

651–652. SEMINAR IN TOPOLOGY

Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor. Hours to be arranged. Fall term, Mr. Berstein. Spring term, Mr. Kahn.

653–654. ADVANCED TOPOLOGY

Throughout the year. Credit four hours a term. Prerequisite: 551 or consent of the instructor. Hours to be arranged. Mr. Henderson.

A selection of advanced topics from modern algebraic, differential and geometric topology. The content of this course varies from year to year.

659. SYMMETRIC SPACES

Spring term. Credit four hours. Prerequisites: 549–550. Hours to be arranged. Mr. Wang.

Symmetric spaces and their group of isometries. Decomposition theorem. Root system associated to a symmetric pair. Geometrical properties of irreducible symmetric spaces. Symmetric Kähler manifolds.

667. ALGEBRAIC GEOMETRY

Spring term. Credit four hours. Prerequisiites: 500 and 531. Hours to be arranged. Mr. Lichtenbaum.

Affine and projective varieties. Divisors. Riemann-Roch theorem. Introduction to schemes.

[352. ELEMENTARY TOPOLOGY]

Spring term. Credit four hours. Prerequisite: 221 or 331. Not offered in 1967–68.

[661–662. SEMINAR IN GEOMETRY]

Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor. Not offered in 1967–68.

[663. MANIFOLDS]

Throughout the year. Credit four hours a term. Prerequisite: 551. Not offered in 1967–68.

[655–656. HOMOTOPY THEORY]

Throughout the year. Credit four hours a term. Prerequisite: 551. Not offered in 1967–68.

PROBABILITY AND STATISTICS

472. STATISTICS

Spring term. Credit four hours. Prerequisites: 371 and knowledge of linear algebra such as taught in 221. M W F 12:20. Preliminary examinations will be held at 7:30 P.M. on Feb. 14, Mar. 6, Apr. 3, May 1. Mr. Kiefer.

Classical and recently developed statistical procedures are discussed in a framework which emphasizes the basic principles of statistical inference and the rationale underlying the choice of these procedures in various settings. These settings include problems of estimation, hypothesis testing, large sample theory, experimental designs, sequential analysis and multiple decision problems. (See also the description of 370 in the *Announcement of the College of Arts and Sciences* and 572.)

571. PROBABILITY

Fall term. Credit four hours. Prerequisite: 412 or, with consent of the instructor, 416 or 422. M W F 12:20. Examinations and make-up lectures, when necessary, will be held on Thursday evenings at 7:30 P.M. Mr. Wolfowitz.

Fundamentals. Combinatorial problems. Distribution functions in one or several dimensions. Important probability laws. Expectation, moments, and characteristic functions. Stochastic convergence and the law of large numbers. The central limit theorem.

572. STATISTICAL ANALYSIS

Spring term. Credit four hours. Prerequisite: 571. M W F 12:20. Mr. Wolfowitz.

A continuation of 571. Topics include an introduction to the theory of point estimation; consistency, efficiency, and sufficiency, and the method of maximum likelihood; the classical tests of hypotheses and their power; the theory of confidence intervals; the basic concepts of statistical decision theory; the fundamentals of sequential analysis.

Intended to furnish a rigorous introduction to mathematical statistics, the course is prerequisite to all advanced courses in statistics.

574. ADVANCED PROBABILITY

Spring term. Credit four hours. Prerequisite: 571. M W F 11:15. Mr. Spitzer.

A continuation of Math 571. Selected topics from Volumes 1 and 2 of Feller, *An Introduction to Probability Theory*. Modern limit theorems, discrete and selected continuous parameter Markov chains, related topics in semigroups and resolvents, ergodic and renewal theorems with applications.

671–672. SEMINAR IN STATISTICS

Throughout the year. Credit four hours. Prerequisite: consent of the instructor. M 4–6. Fall term, Mr. Metivier. Spring term, Mr. Augustin.

675. STATISTICAL ESTIMATION

Fall term. Credit four hours. Prerequisite: 572. Hours to be arranged. Mr. Brown.

Randomization, sufficiency, completeness, minimum variance estimators. Derivation of sequential minimax estimators by the methods of differential inequalities, Bayes solutions, and invariance. The Neyman-Pearson theory of testing hypotheses and interval estimation.

676. DECISION FUNCTIONS

Spring term. Credit four hours. Prerequisite: 675. Hours to be arranged. Mr. Brown.

Wald's theory of decision functions. Multidecision problems. Existence theorems, complete class theorems, and other general decision theoretic results. Optimum character of the sequential probability ratio test. Recent developments.

679. SEMINAR IN MATHEMATICAL ECONOMICS (ECONOMICS 685).

Spring term. Credit four hours. Prerequisite: consent of the instructor. F 4–6. Messrs. Wolfowitz and Stigum.

The main topics to be covered are general economic equilibrium, stability of equilibria, and the theory of value under conditions of uncertainty.

[575. INFORMATION THEORY]

Fall term. Credit four hours. Prerequisite: 411, or, with consent of the instructor, 416 or 421. Not offered in 1967–68.

[673. ANALYSIS OF VARIANCE]

Fall term. Credit four hours. Prerequisite: 572. Not offered in 1967–68.

[674. DESIGN OF EXPERIMENTS]

Spring term. Credit four hours. Prerequisite: 673. Not offered in 1967–68.

[677–678. STOCHASTIC PROCESSES]

Throughout the year. Credit four hours a term. Prerequisite: 512, 571 or consent of the instructor. First term prerequisite to second. Not offered in 1967–68.

MATHEMATICAL LOGIC

581–582. LOGIC

Throughout the year. Credit four hours a term. Prerequisite: 412, 432 or consent of the instructor. M W F 11:15. Mr. Morley.

A study of elementary and advanced topics in mathematical logic. Theorems of Herbrand, Gentzen, Church, and Gödel on provability and undecidability. Theory of recursive functions and recursively enumerable sets.

681–682. SEMINAR IN LOGIC

Throughout the year. Credit four hours a term. Prerequisite: consent of the instructor. Hours to be arranged. Fall term, Mr. Platek. Spring term, Mr. Garfunkel.

683. THEORY OF MODELS

Fall term. Credit four hours. Prerequisites: 581–582. Hours to be arranged. Mr. Morley.

[685. METAMATHEMATICS]

Spring term. Credit four hours. Prerequisite: 482. Not offered in 1967–68.

690. SUPERVISED READING AND RESEARCH

MECHANICAL ENGINEERING

Faculty: John F. Barrows, John F. Booker, Arthur H. Burr, Bart J. Conta, Terrill A. Cool, David Dropkin, George B. DuBois, Howard N. Fairchild, Benjamin Gebhart, Roger L. Geer, Sidney Leibovich, Howard N. McManus, Jr., Franklin K. Moore, Richard M. Phelan, Dennis G. Shepherd, Robert L. Wehe.

Field Representative: David Dropkin, 214 Upson Hall.

MAJOR SUBJECTS

Machine Design
Thermal Power
Thermal Processes

MINOR SUBJECTS

Machine Design
Materials Processing
Thermal Power
Thermal Processes

The Graduate Field of Mechanical Engineering is composed of two departments — the Department of Machine Design and the Department of Thermal Engineering. The Machine Design Department is in charge of the machine design and materials processing subjects; the Thermal Engineering Department is in charge of thermal power and thermal processes subjects.

Considerable latitude is allowed in the selection of the minor subjects. It is generally expected, however, that a major in thermal engineering be combined with a minor from some other department. Appropriate minor subjects, such as mathematics, nuclear engineering, electrical engineering, etc. may be taken in other divisions of the University.

ADMISSION REQUIREMENTS. As a prerequisite for graduate study leading to the degree of M.S. or Ph.D. in the Field of Mechanical Engineering, the candidate should hold a Bachelor's degree and should have the equivalent of the fundamental work required in an accredited undergraduate curriculum in the area of his major work. Those lacking some of the necessary subject matter may be required to take one or more undergraduate courses or do assigned work to make up the deficiency.

LANGUAGE REQUIREMENTS. There is no foreign language requirement for the M.S. degree. A Ph.D. candidate must demonstrate either: (1) reading ability in two languages in addition to his native language, or (2) reading and speaking ability in one language in addition to his native language, or (3) exceptional reading ability in one language in addition to his native language. Required languages shall be chosen from French, German, Russian, or others to be approved by petition to the Field.

EXAMINATIONS. A final comprehensive examination is required for the M.S. degree. For the Ph.D. degree the student must take: (a) a qualifying examination (this may be combined with the examination for the M.S.); (b) the Admission to Candidacy Examination, a general examination of subject matter taken approximately at the time he completes his course work; and (c) a final examination which is primarily concerned with the doctoral dissertation.

MACHINE DESIGN. Unique instruction is offered in design and related subjects, including materials processing. The thesis and courses may be concentrated in one of the following areas or may overlap them: (1) design and development of a new machine or component, (2) analysis of an existing machine or component, (3) experimental investigation to determine design data and machine or tool performance.

The department has its own laboratories for stress, vibration, and endurance testing of machine parts, and for the study of controls. It is particularly well equipped for studies of lubrication phenomena in journal bearings, and for studies requiring use of analog computers. The materials processing laboratory includes many special production machines and gaging devices, and instrumentation for tool forces and temperatures.

Interests of the design staff are necessarily broad, and they overlap in a number of cases. However, based on current activities, they may be grouped as follows:

Hydrodynamic lubrication: John F. Booker, Robert L. Wehe.
Manufacturing engineering: George B. DuBois, Roger L. Geer.
Product design: George B. DuBois, Robert L. Wehe.
Stress and force analysis of mechanical components: Arthur H. Burr, Richard M. Phelan.

Vibration and controls: John F. Booker, Arthur H. Burr, Richard M. Phelan, Robert L. Wehe.

Students who major or minor in machine design usually take their other work in engineering mechanics, materials, materials processing, control systems and servo-mechanisms, mathematics, thermal engineering, agricultural engineering, or industrial engineering. Those minoring in materials processing may take supplementary studies in the Department of Materials Science and Engineering.

THERMAL ENGINEERING. There are excellent opportunities for both analytical and experimental studies at the graduate level in thermal engineering. The approved major and minor subjects are in two areas of special interest to the staff.

Under the subject, thermal processes, studies may be carried out in the areas of (1) fluid dynamics, including high-temperature and nonequilibrium effects, viscosity, radiative transfer, and plasma processes: John F. Barrows, Terrill A. Cool, Sidney Leibovich, Franklin K. Moore. (2) Heat transfer, including stability of convective flows, two-phase flows, boiling heat transfer, ablative heat transfer: David Dropkin, Benjamin Gebhart, Howard N. McManus, Jr. (3) Thermodynamics, including aspects of classical, statistical, and irreversible thermodynamics of concern in present-day technology: Bart J. Conta, Terrill A. Cool.

Under the heading thermal power, studies may be made of direct energy conversion, propulsion and nuclear power problems, use of solar energy, turbomachinery, combustion engines, air conditioning and refrigeration, and heat pumps: Bart J. Conta, David Dropkin, Howard N. Fairchild, Dennis G. Shepherd.

In the laboratories of the School of Mechanical Engineering, instrumentation and equipment are available for the study of thermal processes and performance of engineering components and systems. In addition to the customary instruments, such as spectrometers, oscillographs, potentiometers, hot-wire anemometer, etc., the laboratory possesses a large Mach-Zehnder Interferometer of very high precision, a plasma arc generator capable of producing plasmas with high enthalpies and temperatures up to 25,000°F, and a solar collector apparatus suitable for thermal radiation studies. Several fans and compressors are available for a range of air flow, together with a gas-fired steam generating unit.

By a choice of his minor subject or subjects, the thermal engineering major may study at an advanced level in basic sciences, such as mathematics, physics, and chemistry, or in related engineering areas, such as aerospace engineering, chemical engineering, electrical engineering, applied physics, materials science, and theoretical and applied mechanics. The graduate student will ordinarily find it desirable to enroll in a number of the elective courses offered in the Department of Thermal Engineering, and he will be expected to participate in department seminars attended by students, staff, and visitors.

Fellowships and Scholarships

In addition to the fellowships and scholarships that are available to all students in open competition, the following are restricted to M.S. and Ph.D. candidates majoring in the Field of Mechanical Engineering: Esso Education Foundation Fellowship, John McMullen Graduate Fellowship, Procter and Gamble Fellowship, George B. Upton Fellowship, Edgar J. Meyer Scholarship, Sibley Scholarship. (See pages 14–17.)

Professional Degree

The degree, Master of Engineering (Mechanical), is available as a curricular type of professional degree, the general requirements for which are stated in the *Announcement of the College of Engineering*. Of the thirty credit hours required, the mechanical engineering program allows nine elective hours, together with considerable latitude in the choice of a laboratory course and the design project. In this way, an option is possible in a particular area, e.g., machine dynamics and control, mechanical analysis and development, vehicles and propulsion, propulsion engines, thermal environment, thermal power, thermal processes, manufacturing engineering, material removal, etc.

The professional degree, M.Eng.(Mech.), may be earned in a minimum of two terms of full-time study by the successful completion of the course requirements.

Courses

3055. ADVANCED MECHANICAL ENGINEERING DESIGN

Credit three hrs. Spring. One lecture, two design periods. Prerequisite: 3054, Design of Mechanical Engineering Systems, or equivalent. Intended for graduate students. Staff and guest lecturers.

Design of mechanical engineering systems, components, and equipment in the widest sense, requiring the integration of engineering disciplines at an advanced level.

3090. MECHANICAL ENGINEERING DESIGN PROJECT

Credit three hrs. Spring. Intended for students in the M.Eng.(Mech) program. Staff.

Design of an engineering system or a device of advanced nature. Projects to be carried out by individual students or by small groups with individual assignments culminating in an engineering report by each student.

3116. INTRODUCTION TO INDUSTRIAL DESIGN

Credit three hrs. Fall. Two laboratories. Prerequisite: permission of the instructor.

Readings; abstract and applied design problems which investigate and apply the interrelationships existing between form, function, and materials.

3361. ADVANCED MECHANICAL ANALYSIS

Credit three hrs. Fall. Three recitations. Prerequisite: 3322 or 3331.

Theory of film-lubricated bearings; advanced analysis of special friction devices; theories of failure and design equations; prestressing; impact; thermal stresses and creep; selected topics from advanced strength of materials such as built-up cylinders, rotors, plates, shells, beams on elastic foundations, etc.

3362. MECHANICAL DESIGN OF TURBOMACHINERY

Credit three hrs. Spring. Three recitations. Prerequisites: 3361 and 3324.

Mechanical design of major components of high speed compressors and turbines for structural adequacy and vibration-free operation. Selected topics from among the following: design of rotor components, disks, vanes, blades, shafts, and connections. Design of bearings, seals, gaskets, expansion members. Investigation of natural frequencies and critical speeds. Selection of materials Attention is called to a companion course 3663.

3364. DESIGN FOR MANUFACTURE

Credit three hrs. Fall. Three recitations, one design or laboratory period. Prerequisites: 3322 or 3331, and 3431 or equivalent, or permission of the instructor. Messrs. DuBois and Geer.

Principles and methods of design to improve the producibility of machines and products. Design techniques to simplify and improve the processing operations, to reduce cost, and to increase accuracy and reliability. Designs and operation sequences for small-lot and large-lot manufacture to exploit the capabilities inherent in machine tools, jigs and fixtures, and other production equipment. Applications of the foregoing by design exercises.

3366. ADVANCED KINEMATICS

Credit three hours. Fall. Two recitations, one computation period. Prerequisite: 3321.

Advanced analytical and graphical determination of velocities and accelerations in mechanisms. Special geometrical concepts on the kinematics of mechanisms. Synthesis of linkages by graphical and analytical methods. Design of linkages to give prescribed paths, positions, velocities, and accelerations.

3368. MECHANICAL VIBRATIONS

Credit three hrs. Spring. Two recitations, one laboratory. Prerequisite: 3324 or equivalent. Mr. Burr or Mr. Phelan.

Further development of vibration phenomena in single and multi-degree of freedom linear and nonlinear systems, with emphasis on engineering problems involving analysis and design. Also gyroscopic effects, branched systems, random vibrations, impact and transient phenomena, isolation of shock and vibration, and noise and its reduction. Impedance, matrix, and numerical methods. Analog and digital computer solutions and laboratory studies.

3372. EXPERIMENTAL METHODS IN MACHINE DESIGN

Credit three hrs. Fall. One recitation, two laboratories. Prerequisite: 3322 or 3331. Mr. Phelan.

Investigation and evaluation of methods used to obtain design and performance data. Techniques of photoelasticity, strain measurement, photography, vibration and sound measurements, and development techniques are studied as applied to machine design problems.

3374. CONCEPTUAL DESIGN

Credit three hrs. Fall. Three recitations. Prerequisite: 3322 or equivalent. Mr. DuBois.

Conception and initial design of products and machines. Methods to stimulate mechanical ingenuity and improve appearance. Principles of synthesis and creativity employing association, inversion, and other techniques. Sketching, class discussion, and comparative evaluation of solutions.

3375. AUTOMATIC MACHINERY

Credit three hrs. Spring. Two recitations, one field trip. Prerequisite: 3321. Mr. Wehe.

A study of automatic and semiautomatic machinery such as dairy, canning, wire-forming, textile, machine-tool, computing, and printing equipment.

3377. AUTOMOTIVE ENGINEERING

Credit three hrs. Spring. Three recitations. Prerequisite: 3322. Mr. DuBois.

Analysis of various designs for the parts of an automotive vehicle, other than the engine, in relation to its performance; stability, weight distribution,

traction, steering, driving, braking, riding comfort, power required and available, transmission types, acceleration, and climbing ability. Recommended together with Course 3670 for a study of automotive engineering.

3378. AUTOMATIC CONTROL SYSTEMS

Credit three hrs. Spring. Two recitations, one laboratory. Prerequisite: 3324 or equivalent. Mr. Booker.

Further development of feedback control theory, including stability criteria, frequency response, and transfer functions, with emphasis on engineering problems involving the analysis of existing control systems and the design of systems to perform specified tasks. Also, nonlinear systems, describing functions, sampled-data systems, and compensation techniques. Analog computer simulation and laboratory studies of hydraulic, pneumatic, and electromechanical components and systems.

3380, 3381. DESIGN OF COMPLEX SYSTEMS

Credit three hrs. Fall, spring. Two meetings of two hours per week to be arranged. Intended for graduate students in engineering. Permission of instructor required for registration. Mr. Wehe.

A seminar course relying heavily on student participation in discussing frontier problems such as systems for space and underwater exploitation, salt water conversion, and transportation. Determination of specifications for these systems to meet given needs. Critical discussion of possible solutions based on technical as well as economic and social considerations. Reports will be required containing recommendations and reasoning leading to these considerations.

3382. HYDRODYNAMIC LUBRICATION

Credit three hrs. Three recitations. Mr. Booker.

Design to acquaint those having a general knowledge of solid and fluid mechanics with the special problems and literature currently of interest in various fields of hydrodynamic lubrication. General topics include equations of viscous flow in thin films, self-acting and externally pressurized bearings with liquid and gas lubricant films, bearing system dynamics, digital and analog computer solutions. Also selected special topics in elastohydrodynamic, thermohydrodynamic, and magnetohydrodynamic lubrication.

3451. MATERIAL REMOVAL SYSTEMS

Credit three hrs. Fall. One lecture, two laboratories. Prerequisites: 3431 and 6316. Mr. Geer.

Advanced study of mechanics of chip formation. Forces and power dynamometry. Orthogonal and three dimensional relationships. Cutter geometry and chip control. Nonchip techniques using chemical, electrical, ultrasonic, and other media; surface characteristics; and postprocess treatments.

3461. QUALITY ASSURANCE SYSTEMS

Credit three hrs. Either term. Two lectures, one laboratory. Prerequisites: 3431 and 9170. Mr. Geer.

Theory and computational techniques for control by attributes or variables. Machine tool capability studies, instrumentation systems. Standards codes and applications. Equipment performance characteristics. Fixed and comparative gaging systems; non-contact, reflective, and radiation principles. Surface texture phenomena. True-position tolerancing and charting.

3475. NUMERICAL CONTROL OF PROCESSES

Credit three hrs. Spring. Two lectures, one laboratory-computation. Prerequisite: 3431. Mr. Geer.

A thorough study of concepts, systems, and component designs for flexible-programmed processing. Machine tools as related to numerical control. Machine command-response factors, stick-slip, resonance, shaft windup, mass-inertia, and other effects. Positioning control systems and coding. Manual and computer programming. Simulation studies.

3651. ADVANCED THERMAL SCIENCE

Credit three hrs. Fall. Three recitations. Prerequisites: 3622, 3623, and 3625, or equivalent. Intended for graduate students in the M.Eng.(Mech.) program. Staff.

Advanced level study of topics from thermodynamics, fluid mechanics, and heat transfer. Selection of subjects from irreversible thermodynamics, statistical mechanics, real gas behavior, chemical thermodynamics, unsteady flow phenomena, gas dynamics, shock tube analysis, turbulent flow of jets and wakes, compressible boundary layer, numerical methods, and variable transport properties.

3652. COMBUSTION THEORY

Credit three hrs. Spring. Three lectures. Prerequisite: 3625. Mr. McManus.

Application of the basic equations of fluid flow and heat and mass transfer to homogeneous and diffusion flames. Ignition, quenching, rate processes, and dissociation effects will be examined. Consideration will be given to flame stabilization and practical systems.

3653. REFRIGERATION

Credit three hrs. Fall. Three recitations. Prerequisite: 3625, or 3625 concurrently. Mr. Fairchild.

Introduction to refrigeration with emphasis on application of thermodynamics, fluid dynamics, and heat transfer. Cycle and component performance. Applications in air conditioning and cold storage. Overall performance under varied operating conditions. Cryogenic refrigeration; gas liquefaction, purification, storage, and special heat transfer problems. Thermoelectric cooling.

3654. AIR CONDITIONING

Credit three hrs. Spring. Three recitations. Prerequisite: 3625 or 2625 concurrently. Mr. Fairchild.

Introduction to air conditioning with emphasis on application of thermodynamics, fluid dynamics, mass transfer, and heat transfer. Psychrometrics, air conditioning processes and cycles. Heat transmission in buildings; solar effects; lumped thermal circuit methods. Heat pumps. Air distribution. Component and system performance.

3661. ADVANCED THERMODYNAMICS

Credit three hrs. Fall. Three lectures. Prerequisites: 3621 and 3622, or equivalent. Mr. Conta.

A rigorous and general treatment of classical thermodynamics with emphasis on mathematical developments and philosophical interpretations. The several statements of the concepts and laws of thermodynamics and equivalence proofs, the pure substance, homogeneous and heterogeneous systems. Potential functions and Maxwell's relations, availability, irreversibility, and equilibrium. Entropy flow, entropy production, and irreversible thermodynamics. The relationship between classical thermodynamics, classical statistics, quantum statistics, and information theory.

3663. TURBOMACHINERY

Credit three hrs. Fall. Three recitations. Prerequisites: 3622 and 3623, or permission of the instructor. Mr. Shepherd.

Aerothermodynamic design of turbomachines in general, followed by consideration of specific types; fans, compressors, and pumps; steam, gas, and hydraulic turbines. Energy transfer between a fluid and a rotor; flow in channels and over blades. Compressible flow, three-dimensional effects, surging and cavitation. Outline design of a high-performance compressor-turbine unit. Attention is drawn to 3362 as a companion course for mechanical design.

3664. INTERMEDIATE FLUID MECHANICS

Credit three hrs. Spring. Three recitations. Prerequisite: 3623.

Integrated development of equations of mass, motion, and energy for fluid particles and control volumes. Applications of these governing relations to various selected areas such as hydrodynamics and conformal transformations in ideal flows; laminar and turbulent flows; boundary layers with energy transfer; two-dimensional compressible flows; variable property flows; unsteady one-dimensional flows; other topics of current interest.

3665. TRANSPORT PROCESSES

Credit three hrs. Fall. Three recitations. Prerequisites: basic thermodynamics and fluid mechanics. Mr. Gebhart.

Description of basic microscopic modes of thermal and mass diffusion. Molecular transport mechanics in gases. Formulation of the transport equations and their application to engineering problems. Conduction and mass diffusion in solids, boundary value problems. Thermal radiation between opaque surfaces in vacuum and as a diffusion process in nonopaque media. Mass and energy diffusion by molecular and by eddy processes in convection. Analytical methods in convection investigated, limits shown, and the role of correlations discussed. Analogous phenomena. Combined mode heat transfer.

3667. TECHNIQUES OF THERMAL MEASUREMENT

Credit three hrs. Spring. Two lectures, one laboratory. Prerequisite: 3625. Mr. Dropkin.

Theory, construction, calibration, and application of liquid-in-glass thermometers, solid expansion thermometers, pressure-spring thermometers, resistance thermometers, thermoelectric thermometers, optical pyrometers, radiation pyrometers, enthalpy probes, heat flux probes.

3670. ADVANCED COMBUSTION ENGINES

Credit three hrs. Spring. Three recitations. Prerequisite: 3669, or equivalent. Mr. Fairchild.

Advanced study of topics in field of reciprocating engines, both spark-ignition and diesel. Methods of thermodynamic analysis and performance prediction for free-piston power plants and supercharged engines. Relation of engine performance characteristics and performance characteristics of automotive vehicles. Recommended together with Course 3377 for study in automotive engineering.

3671. AEROSPACE PROPULSION SYSTEMS

Credit three hrs. Spring. Three recitations. Prerequisites: 3622 and 3623, or permission of the instructor. Mr. Shepherd.

Intended for graduate students and qualified undergraduates. Application of thermodynamics and fluid mechanics to the design and performance of thermal-jet and rocket engines in the atmosphere and in space. Mission

analysis in space as it affects the propulsion system. Consideration of auxiliary power supply; study of advanced methods of space propulsion.

3672. ENERGY CONVERSION

Credit three hrs. Spring. Three lectures. Prerequisite: 3622 or equivalent.

Primarily an analysis of energy conversion devices from a classification into heat engines, chemical engines, and expansion engines. An analysis of each class from the point of view of efficiency and other criteria of performance. A more detailed study of some conventional and some direct energy conversion devices including thermoelectric, thermionic, and photovoltaic converters; and fuel cells. Energy sources and energy storage, applications to terrestrial and space power systems.

3673. ADVANCED FLOW MEASUREMENT

Credit three hrs. Fall. Two lectures, one laboratory. Mr. McManus.

Theory and operation of instruments used in fluid flow investigations; hot wire anemometers; density-sensitive optical systems, transient temperature and pressure measurements; measurements in reacting systems; error analysis and treatment of data.

3674. STATISTICAL THERMODYNAMICS

Credit three hrs. Fall. Three recitations. Prerequisites: 3622 and 3623, or equivalent. Mr. Cool.

Kinetic theory of state and transport properties of gases. Statistical mechanics and thermodynamic probability. Multi-component systems in equilibrium, and introduction to nonequilibrium flows.

3680. ADVANCED CONVECTION HEAT TRANSFER

Credit three hrs. Spring. Three recitations. Prerequisite: 3665 or consent of the instructor. Mr. Gebhart.

Processes of transport of thermal energy, momentum, and mass in fluids are considered in detail. Theories of transfer processes and analytic solutions. Analytical and experimental results compared. Transport equations for a fluid, delineation of kinds of processes, differential similarity, natural convection, forced convection at low and high velocities. Boundary layer solutions, similarity theories, and effects of turbulence. Transport in rarefied gases.

3681. RADIATIVE TRANSFER

Credit three hrs. Fall. Three recitations. Prerequisite: 3665 or consent of the instructor. Mr. Moore.

Theory of radiative transfer of heat. Absorption and scattering; differential approximation; surface interactions. Application to atmospheres, steady and transient slab problems; effects on shock and sound wave structure, and hypersonic flow problems. Some assignments to review current literature.

3682. SEMINAR IN HEAT TRANSFER

Credit three hrs. Spring. Two meetings of two hours per week to be arranged. Prerequisite: permission of professor in charge. Mr. Gebhart.

Discussion of fields of active inquiry and current interest in heat transfer. Considerations of major recent work and several summaries of associated contributions.

3683. VISCOUS FLOW THEORY

Credit three hrs. Fall. Three recitations. Prerequisite: 3664 or permission of the instructor. Mr. Barrows.

Stress and rates of deformation tensors, derivation of the Navier-Stokes equations. Exact solutions, very slow motion, boundary layers, Tollmien-Schlichting and Taylor instability, turbulence.

MEDICAL SCIENCES (GRADUATE SCHOOL OF MEDICAL SCIENCES)

Biomathematics

A new program of applied mathematics in biology is offered by the Biomathematics Division to students whose primary interests are mathematical or theoretical, but who wish to concentrate on biological applications. Programs leading to the Ph.D. degree are flexible to suit the particular area of biological application of the individual student, and appropriate courses of study in the relevant aspects of biology, chemistry, physics, and medicine are planned accordingly.

Biophysics

Graduate work toward the Ph.D. degree in Biophysics and the M.S. in Radiation Physics is offered, as well as opportunities for postdoctoral research in Biophysics. Active research programs are being conducted in fundamental radiation biophysics, including cellular radiobiology, and in the biophysics of membrane transport.

Biostatistics

The graduate biostatistics program offered by the Biomathematics Division applies the quantitative methods of the theory of probability and statistics to biological or medical problems. The use of modern computers is an integral part of the program which leads to the Ph.D. degree.

NUCLEAR SCIENCE AND ENGINEERING

Faculty: K. Bingham Cady, David D. Clark, Trevor R. Cuykendall, David Dropkin, Charles D. Gates, John P. Howe, Simpson Linke, Raphael M. Littauer, Ross McPherson, George H. Morrison, Wilbur E. Meserve, Mark Nelkin, Robert L. Von Berg.

Visiting Professor: Frank Feiner

Field Representative: Ross McPherson, Nuclear Reactor Laboratory.

MAJOR SUBJECTS	MINOR SUBJECT
Nuclear Science	Nuclear Engineering
Nuclear Engineering	

ADMISSION REQUIREMENTS. A Bachelor's degree in science or engineering including one year of advanced calculus and a one-year course in atomic and nuclear physics. Students with less preparation may be admitted if their

undergraduate performance is outstanding, but they should expect to take longer to complete the degree requirements. Applicants who are United States citizens are normally expected to apply for the Atomic Energy Commission Special Fellowships in Nuclear Science and Engineering. Applications may be obtained from the Fellowship Office, Oak Ridge Institute for Nuclear Studies, Oak Ridge, Tennessee 37831.

LANGUAGE REQUIREMENTS. The language requirement for the Ph.D. is a reading knowledge of one language other than English. There is no language requirement for the M.S.

EXAMINATION REQUIREMENTS. Before the beginning of his second term of graduate study the student is expected to form his Ph.D. Special Committee. This committee will normally be composed of (1) a chairman, who will be the student's major advisor, (2) a faculty member representing a minor subject outside the Field, and (3) a second member of the Field faculty appointed by the Field Representative. Additional members representing other minor subjects are permitted. As soon as the committee is formed it will administer an informal oral examination designed primarily to guide the course of the student's future study and research. Before the end of the fifth term of graduate study, the committee will administer the Admission to Candidacy Examination. This examination is both written and oral, and covers the core of the graduate course program. Advanced courses in special topics will be taken by most students after this examination, but the passing of this examination signifies a shift in primary emphasis from course work to research.

Research and Study Opportunities

Research and development connected with nuclear energy requires knowledge of a number of scientific and engineering disciplines. Thus the organization of the program permits and encourages this kind of interdisciplinary study, training, and research. Work involving nuclear phenomena, radiation, isotope production, and the like will be done for the most part in the Nuclear Reactor Laboratory which was designed specifically for this purpose. At the present time, five faculty members and all graduate students in Nuclear Science and Engineering work in this laboratory.

The Nuclear Reactor Laboratory was occupied in 1961 and contains: (1) a TRIGA reactor which may be operated steadily at 100 kw producing a neutron flux of 1 to 5 x 10^{12}/cm^2-sec. In addition, the reactor may be pulsed to a peak power of approximately 250 megawatts for the study of phenomena of fairly short duration. The width of the pulse at half maximum is approximately 40 millisec. Eight beam ports and a thermal column allow flexible use of neutrons and radiation. (2) A Zero Power Reactor critical facility of versatile design for basic studies of reactor physics. (3) Subcritical assemblies for similar studies. (4) A shielded cell for chemo-nuclear work with up to 10,000 curie gamma sources and other radioactive materials. Accompanying laboratory space permits work with radioactive materials at low levels. (5) A 3 MeV high current Cockroft Walton accelerator for studies of radiation effects and low energy nuclear levels and reactions has been in operation since 1964.

Faculty research interests are:

K. Bingham Cady: nuclear engineering, reactor physics

David D. Clark: nuclear and reactor physics, radiation detection

Trevor R. Cuykendall: nuclear engineering
David Dropkin: heat transfer, thermal processes
Frank Feiner: nuclear and reactor physics
Charles D. Gates: radioactive waste disposal, sanitary engineering
John P. Howe: thermionic energy, conversion, nuclear materials
Simpson Linke: energy conversion
Raphael M. Littauer: nuclear instrumentation, pulse electronics
Ross McPherson: nuclear physics and nuclear chemistry
George H. Morrison: low level analysis by neutron activation and other methods
Wilbur E. Meserve: control theory
Mark Nelkin: neutron scattering, transport and kinetic theory
Robert L. Von Berg: radiation chemistry, chemical engineering

Examples of current research topics in nuclear science are: nuclear isomers of 0.01 to 10 sec half-life produced by pulsed TRIGA reactor; neutron spectroscopy below 1 MeV; the theory of slow neutron inelastic scattering from liquids; kinetic theory of time dependent correlations in fluids.

Current examples in nuclear engineering include: basic reactor dynamics; pulsed neutron experiments in multiplying media; theory and measurement of neutron importance; space dependent reactor kinetics and noise analysis; stochastic theory of neutron transport; thermionic energy conversion; radiation chemistry.

The detailed program of studies is not prescribed as a curriculum, but is planned by each individual student and the faculty members of his Special Committee. There is, however, a core of subject matter common to study in this Field. This includes the material covered in courses 8309, 8312, and 8351 as listed in the following, a knowledge of applied mathematics through Mathematics 416 or 423, a knowledge of theoretical physics including the graduate quantum mechanics course, Physics 572, and at least one two-term graduate course sequence in some area of engineering. Students majoring in nuclear engineering will also take additional courses from the following list. Students majoring in nuclear science will normally take additional courses in physics at the graduate level.

Professional Degree

The Master of Engineering (Nuclear) program is a two-term program intended for students who want a terminal degree and for students who want an interim degree before doctoral study in Nuclear Science and Engineering. The program develops the basic principles of nuclear reactors and shows a student how his field of undergraduate specialization may be applied to nuclear engineering problems. The recommended entrance requirements include:

1. A baccalaureate degree in engineering, applied science, or its equivalent.
2. Physics, including atomic and nuclear physics.
3. Mathematics, including advanced calculus.
4. Thermodynamics.

Students should make every effort to complete the entrance requirements before beginning the program; this may be done in some cases by informal study during the summer. For further information write to Nuclear Engineering Field Representative, Nuclear Reactor Laboratory.

Courses

8309. LOW-ENERGY NUCLEAR PHYSICS

Credit four hrs. Spring. Three lectures. Prerequisite: an introductory course in atomic and nuclear physics, including quantum mechanics. Mr. Clark.

Low energy nuclear physics as an organized body of experimental facts. Properties of ground and excited states of nuclei; models of nuclear structure; low energy nuclear reactions-scattering, absorption, fission, resonance effects, coherent scattering effects. At a level between *Introductory Nuclear Physics* by Halliday, and *Nuclear Physics* by Fermi.

8312. NUCLEAR REACTOR THEORY

Credit four hours. Fall. Three lectures. Prerequisites: one year of advanced calculus and an introductory course in atomic and nuclear physics. Mr. Nelkin.

The physical processes in neutron chain reactors are described. The theory of neutron diffusion and slowing down is developed and applied to these processes. Neutron transport theory is introduced. At the level of *Nuclear Reactor Theory* by LaMarsh.

8313. REACTOR THEORY II

Credit three hrs. Spring. Three lectures. Continuation of 8312, primarily intended for students planning to do research in the fields of reactor physics and reactor engineering. Mr. Cady.

Delayed neutron kinetics, fission product poisoning, nonlinear kinetics, perturbation theory, theory and measurement of neutron importance, temperature coefficients, control rod theory, hydrogenous reactors, neutron transport, and heterogeneous reactor theory. At the level of *The Physical Theory of Neutron Chain Reactors* by Weinberg and Wigner.

[8314. NEUTRON TRANSPORT THEORY]

Credit two hrs. Prerequisite: 8312 or consent of the instructor. Mr. Nelkin. Not offered in 1967–68.

The linear Boltzmann equation describing neutron migration in matter is intensively studied. Topics will vary, but may include Milne's problem, neutron thermalization, deep penetration of radiation, as well as a formal development of approximate methods of solution. At the level of *Neutron Transport Theory* by Davison.

8333. NUCLEAR REACTOR ENGINEERING

Credit four hrs. Fall. Three lectures. Prerequisite: consent of the instructor. Mr. Cady.

A selected set of topics representing the fundamentals of nuclear reactor engineering; energy conversion and power plant thermodynamics, fluid flow and heat transfer, thermal stresses, radiation protection and shielding, materials for nuclear reactors, economics of nuclear power and fuel cycles, instrumentation and control. At the level of *Nuclear Reactor Engineering* by Glasstone and Sesonske.

8334. NUCLEAR ENGINEERING SEMINAR

Credit four hrs. Spring. Prerequisite: 8333. Mr. Cady.

A conceptual design study of a nuclear reactor system. Emphasis on the interplay of requirements of safety and economics in the design of nuclear power systems.

[8336. NUCLEAR MATERIALS (Materials Science 6872)]

Credit three hrs. Spring. Three lectures. Prerequisites: materials science, physical chemistry or equivalent, and consent of the instructor. Mr. Howe. Not offered in 1967–68.

Application of materials science to choice and design of systems used in nuclear reactors. Emphasizes effects of basic phenomena, conditions or variables encountered in reactors such as irradiation, temperature, temperature differences, composition, and structure. Brings in preparation, fabrication, and use of reactor materials and components.

8351. NUCLEAR MEASUREMENTS LABORATORY

Credit four hrs. Either term. Two two-and-a-half-hour afternoon periods. Prerequisite: some knowledge of nuclear physics. Messrs. Clark and McPherson.

Laboratory experiments plus lectures on interaction of radiation with matter and on radiation detection, including electronic circuits. Some twenty different experiments are available in the areas of nuclear and reactor physics. Among these are experiments on emission and absorption of radiation; on radiation detectors and nuclear electronic circuits; on interactions of neutrons with matter (absorption, scattering, moderation, and diffusion); on activation analysis and radiochemistry; and on properties of a subcritical assembly. Many of the experiments use the TRIGA Reactor. The student is expected to perform eight to ten experiments, selected to meet his needs.

8352. ADVANCED NUCLEAR AND REACTOR LABORATORY

Credit three hrs. Either term. Two two-and-a-half-hour afternoon periods. Prerequisites: 8351 and 8309 or 8312. Messrs. Clark and McPherson.

Laboratory experiments plus lectures on experimental methods in nuclear physics and reactor physics. Some ten different experiments are available, among them one using the Zero Power Reactor critical facility.

OPERATIONS RESEARCH

Faculty: Robert E. Bechhofer, Richard H. Bernhard, Richard W. Conway, Hamilton Emmons, Henry P. Goode, Kenneth O. Kortanek, William L. Maxwell, Narahari U. Prabhu, Sidney Saltzman, Martin W. Sampson, Byron W. Saunders, Andrew Schultz, Jr., Howard M. Taylor 3d, Lionel Weiss.

Field Representative: William L. Maxwell, 366 Upson Hall.

MAJOR AND MINOR SUBJECTS

Applied Probability and Statistics
Industrial Engineering
Information Processing
Operations Research
Systems Analysis and Design

A general description of the five subjects is given below.

APPLIED PROBABILITY AND STATISTICS. This subject is intended for those students whose primary interests lie in the development of new methodology in probability and statistics, particularly insofar as these techniques are applied to problems arising in engineering and sciences. Thus, for example, applied probability is concerned with problems in queuing theory, inventory theory, reliability theory, and time series analysis; applied statistics

deals with problems in the design, analysis, and interpretation of experiments, statistical control theory and sampling inspection, and statistical decision theory. Students who elect work in this subject are expected to acquire a deep knowledge of the theory underlying the various techniques; the doctoral dissertation shall represent a fundamental contribution to theory and application. All students who major in this subject are required to minor in mathematics.

INDUSTRIAL ENGINEERING. This subject is concerned with studies in the analysis and design of the complex operational systems that occur in industry, particularly in manufacturing. Plant design, cost analysis and control, and production planning are some of the major topics which are considered. A high degree of facility is expected with some of the modern analytical techniques which provide tools for rational decision-making, and which aid in the establishment of valid design criteria. Such techniques are drawn from the areas of queuing theory, inventory theory, mathematical programming, statistical control, and computer simulation.

INFORMATION PROCESSING. Information processing is concerned with the design of computing-communication-decision systems for the control of complex operations such as are encountered in manufacturing, transportation, logistics, and institutional management. Such systems are studied in several graduate Fields; the emphasis in this Field is on the analysis of requirements, the development of decision procedures and the overall systems design. A graduate program in information processing will normally include substantial work in the Field of Computer Science.

The Office of Computer Services provides the principal laboratory facility for this area with an IBM 360/65 remote-access computing system.

OPERATIONS RESEARCH. The program in operations research is strongly analytical in approach and content. Emphasis is placed on understanding the phenomena underlying practical problems in order that suitable mathematical models can be developed or selected to represent the operational situation. Such models may be drawn from inventory theory, queuing theory, reliability, replacement and maintenance theory, control theory, decision theory, and mathematical programming theory. The operations research student, motivated by a program which emphasizes the mathematical, probabilistic, statistical, and computational sciences, has interests that are much broader than those associated with industrial problems alone.

SYSTEMS ANALYSIS AND DESIGN. This subject shares with operations research an interest in the development of analytical models to represent the basic structure of operational systems. However, in this case the model is simply a predictive stage of a design task. The objective is not so much the understanding of the mechanism of the model as it is the using of predictions based on the model to compare design alternatives. There is also a distinction in the scale of systems that are considered; the analytical models of operations research often correspond to the components of these larger structures. Typical systems which might be considered would be found in manufacturing, integrated transportation, marketing, highway, and other related systems complete with their control elements.

APPROPRIATE MINOR SUBJECTS. The following minor subjects have been chosen most frequently in recent years: Computer Science (Computer Science), Control Systems Engineering (Electrical Engineering), Econometrics (Economics), Managerial Economics (Business and Public Administration),

Mathematics (Mathematics), Regional Planning (City and Regional Planning), and Water Resources (Water Resources).

ADMISSION REQUIREMENTS. As a prerequisite for graduate study leading to the degree of M.S. or Ph.D. with a major in the Field of Operations Research, the candidate must have been graduated from an institution of recognized standing with a Bachelor's degree in engineering, mathematics, economics, or the physical sciences. In addition, he must have a commendable undergraduate scholastic record and must supply other evidence of his interest in, and ability to pursue, advanced study and research in his major and minor subjects. It is strongly recommended that all applicants to the Field take the Graduate Record Examination and submit the results along with their application for graduate study. Fellowship and assistantship applicants must submit this examination.

LANGUAGE REQUIREMENTS. For the M.S. degree: no language requirement. For the Ph.D. degree a candidate must demonstrate either *(a)* exceptional reading ability in one language additional to his native language, or *(b)* reading ability in two languages additional to his native language.

Required languages shall be chosen from French, German, Russian, or others to be approved by petition to the Field.

PH.D. EXAMINATIONS. In addition to the Admission to Candidacy Examination which will ordinarily be administered by the student's Special Committee during the third year of graduate study, and the Final Examination on the thesis, the student will be given a qualifying examination administered by the Field. This latter examination will normally be taken during the second term of graduate study. It shall serve to determine the ability of the candidate to pursue doctoral studies, and to assist the Special Committee in developing a program of study for the candidate.

Research Interests of the Faculty

R. E. Bechhofer (design of experiments, ranking and selection procedures), R. H. Bernhard (capital investment planning, cost analysis and control), R. W. Conway (computer science, scheduling theory), H. Emmons (systems analysis), H. P. Goode (manufacturing engineering, sampling inspection), K. O. Kortanek (mathematical programming, systems analysis), W. L. Maxwell (data processing and production control systems, computer simulation of manufacturing systems), N. U. Prabhu (queuing and inventory theory, stochastic processes), S. Saltzman (information processing systems, econometrics), M. W. Sampson (industrial organization, methods engineering), B. W. Saunders (manufacturing engineering, materials handling), A. W. Schultz, Jr. (operations research, engineering administration), H. M. Taylor 3d (Markov decision processes, statistical control theory), L. I. Weiss (statistical decision theory, nonparametric statistics).

RESEARCH OPPORTUNITIES. During the academic year 1968–69 several members of the faculty will be engaged in sponsored research on contracts or grants which provide financial support and which offer opportunities for thesis research for advanced graduate students. The research areas include statistical multiple-decision ranking and selection procedures, information processing and operations control systems, multi-echelon logistics, statistical control theory, and sequential procedures and applied stochastic processes.

Departmental Fellowships

In addition to several University-wide and College of Engineering fellowships, the following fellowships are specifically designated for incoming candidates in the Field of Operations Research:

JOHN McMULLEN GRADUATE FELLOWSHIP. $2000 plus tuition and fees.

PROCTER AND GAMBLE FELLOWSHIP. $2000 plus tuition and fees. A $700 allowance is available if the recipient is married.

SUN OIL FELLOWSHIP. $2250 plus tuition and fees if the recipient is single or married without children. A $450 allowance is available if the recipient is married and has children.

DEXTER S. KIMBALL FELLOWSHIP OF CORNELL AERONAUTICAL LABORATORY. $2500 or more plus tuition and fees.

Professional Degree

The professional Master of Engineering (Industrial) degree program is designed for those primarily interested in becoming proficient in the practice of modern industrial engineering. This is a formal "course" program which concentrates on additional analytical and design techniques with special emphasis on their application. To be accepted as a candidate for the Master of Engineering degree, an applicant must (1) hold a Bachelor's degree from an institution of recognized standing in one of the fields of engineering; (2) have an adequate preparation for graduate study in industrial engineering; and (3) show promise of doing well in advanced study as judged by his previous scholastic record or other achievements. Information and applications for this program may be obtained by writing to Professor Byron W. Saunders, Upson Hall.

Courses

9460. INTRODUCTION TO PROBABILITY THEORY WITH ENGINEERING APPLICATIONS

Credit four hrs. Fall. Three lecture-recitations, one computation period. Prerequisite: Mathematics 294 or equivalent.

Definition of probability and basic rules of probability theory. Random variables, probability distributions, and expected values. Special distributions important in engineering work and relations among them; elementary limit theorems. Introduction to stochastic processes and Markov chains, and their applications in the construction of mathematical models of operation, with emphasis on queuing and inventory models.

9470. INTRODUCTION TO STATISTICAL THEORY WITH ENGINEERING APPLICATIONS

Credit four hrs. Spring. Three lecture-recitations, one computation period. Prerequisite: 9460.

The application of statistical theory to problems associated with the analysis of data and inference drawn therefrom. Principles of statistical inference: esti-

mating the value of the unknown parameters of probability distributions, testing hypotheses concerning these parameters; elements of statistical decision theory. Introduction to correlation theory and curve fitting by least squares. Applications in regression, statistical control, and experimentation.

9481. INTRODUCTION TO COMPUTER SCIENCE

Credit three hrs. Spring. Two lectures, one recitation-computation.

Introduction to the Field of Computer Science including principles and characteristics of information processing equipment, programming languages, and applications. Topics are selected to illustrate a wide range of current and potential areas of application with emphasis being placed on the modern digital computer as a symbol manipulating device rather than as an arithmetic calculator. Number systems, computer logic, and organization, and characteristics of current equipment are covered along with various aspects of programming. Introductory concepts and problems associated with using computers in information processing systems, real-time control systems, simulated experimentation, and the design process are also considered.

9510. WORK DESIGN AND MEASUREMENT

Credit three hrs. Fall. Two recitations, one laboratory. Prerequisite: 9310 or permission of the instructor.

An advanced course in the analysis and design of man-micro systems and man-machine micro systems. Advanced statistical treatment of work measurement design, variables measurement, and work sampling; mathematical and statistical treatment of model design, standard data, control, and standards maintenance; study of the micro-systems design problem, including emphasis on the behavioral aspects and wage incentives.

9511. MANUFACTURING ENGINEERING

Credit three hrs. Fall. One lecture, one recitation-computation period. Prerequisite: 9311.

The analysis and design of production facilities based on output requirements of the system. Attention will be directed towards the interaction of processing methods and requirements with handling methods and storage facilities. The effects of various levels of mechanization on operating costs and initial investment will be studied.

9512. STATISTICAL METHODS IN QUALITY AND RELIABILITY CONTROL

Credit three hrs. Spring. Three lectures. Prerequisite: 9470 or equivalent.

Control concepts; control chart methods for attributes and for variables; process capability analysis; attributes acceptance sampling plans and procedures; double and multiple sampling inspection; elementary plans and procedures for variables; acceptance-rectification procedures; basic reliability concepts; exponential and normal distributions as models for reliability application; life and reliability analysis of components; analysis of series and parallel systems; stand-by and redundancy; elementary sampling-inspection procedures used for life and reliability.

9521. PRODUCTION PLANNING AND CONTROL

Credit four hrs. Spring. Three recitations, one computation period. Prerequisites: 9460, and 9320 or equivalent.

Methods for the planning and control of large-scale operations with emphasis on manufacturing systems. Among the areas covered will be sales and production forecasting; manufacturing planning; routing, scheduling and

loading; sequencing; dispatching; planning and control of inventories. Emphasis will be on mathematical and statistical methods for performing these functions; however, the empirical systems and procedures in common use will also be discussed and evaluated.

9522. OPERATIONS RESEARCH I

Credit three hrs. Fall. Three lecture-recitation periods. Prerequisite: permission of the instructor.

Model design, methodology of operations research, linear programming, transportation problem, assignment problem, dual theorem, parametric linear programming, integer programming, nonlinear programming, dynamic programming, introduction to inventory theory; comprehensive problems and case studies.

9523. OPERATIONS RESEARCH II

Credit three hrs. Spring. Three lecture-recitation periods. Prerequisite: 9460 or permission of the instructor.

Models for inventory and production control; replacement theory; queuing, including standard birth and death process model and nonstandard models, application of queuing theory; simulation; game theory; illustrative examples and problems.

9524. PROBLEMS IN OPERATIONS RESEARCH

Credit three hrs. A two-hour meeting a week. Prerequisite: 9523 or equivalent.

An advanced seminar concentrating on problem definition, measures of effectiveness, applicability of various analytical methods to the solution of real problems.

9525. FLOW AND SCHEDULING IN NETWORKS

Credit three hrs. Spring. Three lecture-recitation periods.

Network analysis for continuous static flow; feasibility theorems, capacity determination, minimal cost operation. Sequencing models for deterministic discrete flow networks. Determination of capacity, routing and discipline for networks of queues.

9526. MATHEMATICAL MODELS – DEVELOPMENT AND APPLICATION

Credit four hrs. Fall. Three lecture-recitations, one computation period. Prerequisites: 9311 and 9320 or permission of the instructor.

A detailed examination of probabilistic and deterministic models used in industrial engineering work. Study of some of the standard models found in the literature.

9530. MATHEMATICAL PROGRAMMING

Credit three hrs. Fall. Three lecture-recitation periods. Prerequisite: permission of the instructor.

Theory, methods, computational techniques, and applications of mathematical programming. Classical constrained maximization and Lagrange multipliers. Linear programming; simplex methods and variations; the dual and the dual simplex methods; transportation programming. Integer programming. Quadratic and convex programming. Linear and quadratic assignment programming.

9531. DYNAMIC PROGRAMMING

Credit three hrs. Spring. Three lecture-recitation periods. Prerequisite: 9560.

Dynamic programming as a computational technique for solving a wide variety of problems. Concentration on deterministic problems; the knapsack problem, the obstacle course problem, finite horizon inventory models with known demand. Introduction to Markov sequential decision problems; Howard's algorithm in the finite state and action space case.

9539. SELECTED TOPICS IN MATHEMATICAL PROGRAMMING

Credit three hrs. Spring. Three lecture-recitation periods. Prerequisite: 9530.

Topics will be selected from such areas as nonlinear, stochastic, and semi-infinite programming.

9550. ENGINEERING ECONOMIC ANALYSIS

Credit three hrs. Fall. Three lectures.

An intensive accelerated survey of financial and managerial accounting and engineering economics. Use of cost information for financial reporting, cost control, and decision making. Specific topics include: theory of double-entry accrual accounting as background for subsequent material; bookkeeping is deemphasized. Use of costs in manufacturing: job order vs. process costing; predetermined overhead rates; standard costs and variances. Modification of cost information for decision making: cost dichotomies; profit-volume charts; direct costing; costing of joint products and by-products; economic lot sizes; use of costs in other models of operations research. Capital investment planning: the time value of money; use of interest rates; ranking procedures for proposed projects including the MAPI formulas; handling of risk and uncertainty.

9551. ADVANCED ENGINEERING ECONOMIC ANALYSIS

Credit three hrs. Spring. Three lectures. Prerequisite: 9311 or equivalent.

Topics include: Brief review of use of cost information for financial reporting, cost control and decision making. Intensive discussion of capital investment planning procedures. Problems in project ranking including use of payoff period, present worth, internal rate of return and MAPI urgency rating. Interdependence of productive investment and financing decisions. The cost of capital controversy. Handling of risk and uncertainty. Applications of linear programming to capital budgeting problems. Theory of the firm including objectives, market structure, and pricing policies. Measures of performance. Problems of profit measurement in the decentralized firm including intensive discussion of transfer pricing.

9560. APPLIED STOCHASTIC PROCESSES

Credit three hrs. Spring. Two recitations, one computation period. Prerequisites: 9460 and 9470, or permission of the instructor.

An introduction to stochastic processes, emphasizing basic theory and its engineering application. The following topics are covered: second order processes, covariance function and spectral distribution, Markov chains and processes, diffusion processes, renewal theory and recurrent events, fluctuation theory, random walks, branching processes, queues, Brownian motion, and birth and death processes.

9561. QUEUING THEORY

Credit three hrs. Fall. Two recitations, one computation period. Prerequisites: 9460 and permission of the instructor.

Definition of a queuing process. Poisson and Erlang queues. Imbedded chains. Transient behavior of the systems M/G/1 and GI/M/1. The general queue GI/G/1. Bulk queues. Applications to specific engineering problems such as shop scheduling, equipment maintenance, and inventory control.

9562. INVENTORY THEORY

Credit three hrs. Fall. Three lecture-recitation periods. Prerequisites: 9460 and permission of the instructor.

An introduction to the mathematical theory of inventory and production control with emphasis on the construction and solution of mathematical models; topics will be drawn from the recent technical literature and will include deterministic and stochastic demands; dynamic programming and stationary analyses of inventory problems; renewal theory applied to inventory problems; multi-echelon problems; statistical problems; and production smoothing.

9563. SELECTED TOPICS IN THE THEORY OF QUALITY AND RELIABILITY CONTROL

Credit three hrs. Spring. Three lectures. Prerequisite: 9470 or the equivalent.

This course will concentrate on the statistical properties and derivation of some quality and reliability control procedures. Topics will include the economic design of Shewhart control charts, cumulative sum control charts, Girshick and Rubin control procedures, moving average control charts, sampling inspection by variables for percent defective, reliability estimation, and reliability growth models.

9564. SEQUENTIAL DECISION AND CONTROL PROCESSES

Credit three hrs. Fall. Three lectures. Prerequisite: 9531.

Will concentrate on Markov sequential decision models with general action and state spaces. A careful study of the underlying probabilistic structure. Finite horizon problems, total expected discounted return, optimal stopping, time average return criteria. Study of the existence and characterization of optimal control strategies.

9569. SELECTED TOPICS IN APPLIED PROBABILITY

Credit three hrs. Either term. Three lectures. Prerequisites: 9560 and permission of the instructor.

Selected topics in applied probability for advanced students. Topics will be selected from the current literature in addition to the research areas of the staff.

9571. DESIGN OF EXPERIMENTS

Credit four hrs. Fall. Two recitations, one computation period. Prerequisite: 9470 or permission of the instructor.

Use and analysis of experimental designs such as randomized blocks, Latin squares, and incomplete blocks; analysis of variance and covariance; factorial experiments, confounding, fractional replication; statistical problems associated with finding best operating conditions; response-surface analysis.

9572. STATISTICAL DECISION THEORY

Credit three hrs. Fall. Three recitations. Prerequisite: 9470 or equivalent.

The general problem of statistical decision theory and its applications. The comparison of decision rules; Bayes, admissible, and minimax decision rules. Problems involving a sequence of decisions over time, including sequential analysis. Use of the sample cumulative distribution function, and other nonparametric methods. Applications to problems in the areas of inventory control, sampling inspection, capital investment, and procurement.

9573. STATISTICAL MULTIPLE DECISION PROCEDURES

Credit three hrs. Spring. Two recitations, one computation period. Prerequisite: 9571 or permission of the instructor.

The study of multiple-decision problems in which a choice must be made among two or more courses of action. Statistical formulations of the problems. Fixed-sample size, two-stage, and sequential procedures. Special emphasis on applications to ranking problems involving choosing the "best" category where goodness is measured in terms of a particular parameter of interest. Recent developments.

9579. SELECTED TOPICS IN APPLIED STATISTICS

Credit three hrs. Either term. Two recitations, one computation period. Prerequisite: 9470 or permission of the instructor.

Selected topics chosen from such areas as nonparametric statistical methods, sequential analysis, multivariate analysis.

9580. DIGITAL SYSTEMS SIMULATION

Credit four hrs. Fall. Two lectures, one recitation. Prerequisites: 9481 and 9470, or permission of the instructor.

The use of a program for a digital computer to simulate the operating characteristics of a complex system in time. Discussion of problems encountered in construction of a simulation program; synchronization and file maintenance, random number generation, random deviate sampling. Programming in the CLP and SIMSCRIPT languages. Problems in the design of effective investigations using simulation; statistical considerations when sampling from a simulated process.

9582. DATA PROCESSING SYSTEMS

Credit three hrs. Fall. One lecture, one computation period. Prerequisite: 9481 or permission of the instructor.

The design of integrated data processing systems for operational and financial control; questions of system organization, languages, and equipment appropriate to this type of application, file structures, addressing and search problems, sorting techniques; problems of multiple-remote-input, on-line data processing systems; techniques of system requirement analysis.

9591. OPERATIONS RESEARCH GRADUATE SEMINAR

Credit one hr. Both terms. A weekly one-and-a-half-hour meeting.

Presentation of latest research results by visitors, staff, and advanced graduate students. Discussion and study of assigned topics of importance in the Field.

PHYSICS

Faculty: Vinay Ambegaokar, Neil W. Ashcroft, Karl Berkelman, Hans A. Bethe, Raymond Bowers, Andrew A. Browman, Peter A. Carruthers, David G. Cassel, Geoffrey V. Chester, Robert M. Cotts, John P. Delvaille, John W. DeWire, Donald A. Edwards, Douglas B. Fitchen, Kurt Gottfried, Kenneth I. Greisen, Franz L. Gross, Louis N. Hand, Paul L. Hartman, Donald F. Holcomb, Toichiro Kinoshita, James A. Krumhansl, David M. Lee, Raphael M. Littauer, Herbert Mahr, Bruce W. Maxfield, Boyce D. McDaniel, N. David Mermin, Herbert F. Newhall, Jay Orear, Lyman G. Parratt, Robert O. Pohl, A. Lincoln Read, John D. Reppy, Edwin E. Salpeter, Albert J. Sievers, Robert H. Silsbee, Albert Silverman, Robert L. Sproull, Peter C. Stein, Richard M. Talman, D. Hywel White, John W. Wilkins, Kenneth G. Wilson, Robert R. Wilson, William M. Woodward, and Donald R. Yennie.

Visiting and Ad Hoc Faculty: David D. Clark, Roger A. Cowley, Peter A. Egelstaff, Thomas Gold, Martin O. Harwit, Mark S. Nelkin, Thor N. Rhodin, Henry S. Sack, Watt W. Webb, and George J. Wolga.

Also on the faculty, but not serving on graduate students' Special Committees, are about forty Ph.D. instructors and research associates.

Field Representative: D. Hywel White, 113 Clark Hall and 118 Newman Laboratory.

Research and Study Opportunities

THEORETICAL PHYSICS. Many-body theory, theory of superconductors, theory of metallic state, superfluidity, statistical mechanics and irreversibility, phonon physics and transport processes, low temperature physics, electrodynamic phenomena and defects in solids, dispersion relations and strong interactions — high energy limits, "bootstrap" dynamics, models of reaction processes — internal symmetrics and their connection with strong interaction dynamics, quantum electrodynamics, quantum field theory and renormalization, astrophysics, stellar structure. About half of the theory group is primarily associated with the Laboratory of Nuclear Studies and about half primarily with the Laboratory of Atomic and Solid State Physics; however, continual interaction within the entire group takes place. Professors Ambegaokar, Ashcroft, Bethe, Carruthers, Chester, Egelstaff, Gottfried, Gross, Kinoshita, Krumhansl, Mermin, Nelkin, Salpeter, Wilkins, K. Wilson, and Yennie.

EXPERIMENTAL HIGH-ENERGY NUCLEAR RESEARCH. Photoproduction processes involving intermediate mass mesons and hyperons, energy levels of excited states of the proton, detailed study of the structure of the proton, synchrotron radiation, gamma ray interactions with matter, Compton scattering, photo-disintegration of nuclei, cosmic ray research including air showers and methods of detection of neutral primary radiations, properties of elementary particles, and high-energy interactions. Large machine shop and electronics shop; 2 Gev and 10 Gev electron synchrotrons, etc. Cornell staff and students participate in research with the AGS 30 Gev protron synchrotron at Brookhaven. Professors Berkelman, Browman, Cassel, Delvaille, DeWire, Edwards, Greisen, Hand, Littauer, McDaniel, Orear, Read, Silverman, Stein, Talman, White, R. Wilson, and Woodward.

EXPERIMENTAL ATOMIC AND SOLID STATE PHYSICS. Phonon physics, superconductivity, optical spectroscopy, low-temperature physics, magnetoplasma waves, spin resonance, x ray emission and absorption spectra, electron diffraction, thermal conductivity, and spin relaxation. Large machine shop and glass-blowing shop; several large stable DC magnets, superconducting solenoids, vacuum UV spectrographs, IR to UV monochromators, spin resonance spectrometers, and x ray spectrometers. Available through association with the Materials Science Center of Cornell University are: central facilities for electronics, crystal growing, analytical chemistry, technical operations, high pressure, x ray and metallography, crystal irradiation, and electron microscopy. Professors Bowers, Cotts, Cowley, Fitchen, Hartman, Holcomb, Lee, Mahr, Newhall, Parratt, Pohl, Sack, Sievers, Silsbee, Webb, and Wolga.

SPACE PHYSICS. Astrophysics, stellar structure, cosmic rays, radio astronomy, aurora, and upper atmosphere. Facilities are available through the Cornell Center for Radiophysics and Space Research. These include a lunar surface

laboratory, radio astronomy and ionospheric laboratories, and the radio telescope in the Arecibo Ionospheric Laboratory in Puerto Rico. Professors Delvaille, Gold, Greisen, Harwit, and Salpeter.

APPLIED PHYSICS, MATERIALS SCIENCE, ASTRONOMY AND SPACE SCIENCES, APPLIED MATHEMATICS, ETC. Many of the faculty of the Field of Physics are also members of other Fields and Centers, and, in consequence of the various combinations of interests (majors and minors), respective graduate students are often indistinguishable by fields. Physics faculty and students benefit from the cross-boundary informalities and especially from the availability of much more extensive research facilities.

MAJOR AND MINOR SUBJECTS

For either the Master's or Ph.D. degree in the Field of Physics it suffices to have one minor subject, either inside or outside the Field, but, for the Ph.D. degree, the student's Special Committee may require two minors. If two minors are required, at least one must be outside the Field of Physics. Within the Field of Physics, the possible major and minor subjects are:

MAJOR SUBJECTS	MINOR SUBJECTS
Physics	Physics
Experimental Physics	Experimental Physics
Theoretical Physics	Theoretical Physics

The major or minor subject may be physics only if accompanied by a minor or major subject outside the Field of Physics. A physics major is appropriate when the minor is outside the Field of Physics.

The major subject may be experimental physics only if accompanied by theoretical physics as a minor, and may be theoretical physics only if accompanied by experimental physics as a minor.

Each student has a Special Committee that (a) represents his major and minor interests and (b) serves as an examining and advisory committee. This Special Committee consists of at least three members with at least two from the Field of Physics. The initial committee of three is normally appointed by the Physics Field Representative, but the student himself is expected to choose his "permanent" committee (to replace the appointed committee) as soon as his major and minor interests become reasonably firm. The chairman of the "permanent" committee represents the major and normally, but not necessarily, is the member who supervises the thesis.

ADMISSION. The large majority of entering students have completed the equivalent of an undergraduate physics major program including such junior-senior courses as analytical mechanics, electricity and magnetism, optics and wave motion, electronics, atomic physics, thermodynamics, quantum mechanics, and solid state and nuclear physics. The undergraduate training also typically includes some senior-course laboratory work in physics. Knowledge of differential equations and of vector calculus is essential.

In admitting students, emphasis is on the quality of the undergraduate work and on the promise for graduate work rather than on the extent of undergraduate study in physics and related subjects. It is not unusual that an entering student will enroll in one or more undergraduate courses to make up deficiencies.

Almost all students are admitted directly into the Ph.D. program. (If an applicant's academic background in physics is either deficient or questionable, he may be admitted *provisionally* into the Ph.D. program; this is fairly

common for students from foreign countries.) Some students prefer to work toward the Master's degree either as a terminal degree or on the way toward a Ph D. degree. Most students, however, prefer to proceed directly for the Ph.D. degree.

A student who wishes to interrupt his graduate work with a leave of absence for longer than one year must apply for readmission on the same basis as a new student, i.e., he must obtain the recommendation of the Field Committee on Admissions.

ASSISTANTSHIPS AND FELLOWSHIPS. Essentially all first-year graduate physics students are either teaching fellows or fellowship holders. The faculty emphasizes the training importance of teaching experience and encourages all qualified students to teach. Regular teaching appointments involve about sixteen hours per week, usually in undergraduate classrooms and laboratories or as readers in graduate courses. Any fellowship holder who wishes it, and whose fellowship conditions allow it, may have a teaching appointment, usually with reduced duties and with a reduced (additional) stipend.

Most third-year students are research assistants, nominally 20 hours per week, for work on or closely allied to the student's doctoral thesis which is normally undertaken at the end of the second year of graduate work.

Holding an appointment as a research assistant or a teaching fellow does not significantly delay the completion of the requirements for an advanced degree.

EXAMINATIONS. The graduate examination structure in Physics is as follows: for a Master's degree, the Master's final examination (see, however, the comprehensive Admission to Candidacy Examination for the Ph.D.). For a Ph.D. degree, (a) a qualifying examination taken normally at the beginning of the second year of graduate work, (b) a comprehensive Admission to Candidacy Examination taken normally after the second year of graduate work, and (c) a Ph.D. Final Examination. For a few students making especially good progress their first year, the qualifying examination is oral only; for all others it is written and oral. It may be taken a second time (within a year), but only one re-examination is allowed. If the Admission to Candidacy Examination is passed at a satisfactory Master's level, the Special Committee may at its discretion recommend the award of a Master's degree without a thesis and without further examination. The Ph.D. Final Examination is oral and is confined to the subject of the thesis.

No foreign language is required for a Master's or a Ph.D. degree with a major subject in the Field of Physics. However, a good proficiency in at least one foreign language (preferably Russian, German, or French) is very desirable, and it is strongly recommended that this proficiency be acquired before graduate work is undertaken.

Courses of Instruction

Courses at the undergraduate level are listed in the *Announcement of the College of Arts and Sciences.* Of those, a few junior-senior courses are frequently taken by graduate students whose backgrounds are somewhat deficient. Such courses are Physics 319, 325, 326, 342, 360, 431, 432, 443, 444, and 454.

Graduate physics courses are numbered 500 or higher, and are listed below. Before looking at the courses, note that almost all first-year physics graduate students (essentially all of whom are fellows or teaching fellows) typically take three courses each term; occasionally a fellow takes four courses. Stu-

dents are encouraged to complete their "core" courses (courses to be taken before the Master's final or the Ph.D. Admission to Candidacy Examination) early; to expedite this, with three courses per term, students are urged to take course Physics 510 or 561 or both during the summer *preceding* their first academic year. A typical first-year program for a student having "average" preparation, a program without much leeway, is the following (P ≡ physics and M ≡ mathematics):

First term: P-510; P-561 or 572; M-415.
Second term: P-562; P-572; M-416 or Master's thesis.

In addition to the formal courses, students and staff meet over coffee or tea at weekly physics colloquia and topical seminars. For first-year graduate students a special seminar is held biweekly to acquaint the newcomers with Cornell and the Physics Department. Every graduate student is allotted a study desk in one of the physics buildings, and he is encouraged to assume the life of an active physicist as one of the community as soon as possible. Three factors may be mentioned that help make the Cornell community of physicists a close-knit one — (1) generally common "core" courses, (2) rotation of the professors teaching these courses, and (3) the small college town atmosphere. The professors are generally available for consultation with students.

500. INFORMAL GRADUATE LABORATORY

Either term. Credit one to three hours a term. Associated with the Physics 510 laboratory. Primarily for graduate students who have had at least one year of college physics with laboratory but who do not have the prerequisites for Physics 510. T W or Th F 1:25–4:25. Messrs. Hartman, Batterman, Cassel, Cuykendall, Mahr, Mistry, Reppy, Siegel, Stein, Talman, and Woodward.

505–506. DESIGN OF ELECTRONIC CIRCUITRY

Throughout the year. Credit two hours each term. Prerequisites: Physics 360, Mathematics 315, and familiarity with complex representation of a-c signals, or consent of the instructor. Course 505 is prerequisite to 506. T Th 9:05. Mr. Littauer and staff.

Circuit techniques and design in electronic measurement and instrumentation with emphasis on pulse waveforms. At the level of *Pulse Electronics* by Littauer.

510. ADVANCED EXPERIMENTAL PHYSICS

Either term. Credit three hours per term. Prerequisites: Physics 410 and 443, or consent of the instructor. At least one term of Physics 510 is ordinarily required of every graduate physics student during his first year at Cornell. Laboratory, T W or Th F 1:25–4:25. Instructing staff same as for Physics 500.

About seventy different experiments are available among the subjects of mechanics, acoustics, optics, spectroscopy, electrical circuits, electronics and ionics, heat, x rays, crystal structure, solid state, cosmic rays, and nuclear physics. The student is expected to perform four to eight experiments, selected to meet his individual needs. Stress is laid on independent work.

520. ADVANCED EXPERIMENTAL PROJECTS

Either term. Credit three hours per term. Prerequisites: Physics 510 and consent of the instructor. Hours to be arranged. Mr. Littauer and staff.

Projects of modern topical interest that involve some independent development work by the student. Opportunity for more initiative in experimental work than is possible in Physics 510. One or two projects in different areas typically comprise a term's work (e.g., with the Cornell 2 Gev synchrotron, or with a liquid helium cryostat, or with both.)

561. THEORETICAL PHYSICS I

Fall term. Credit four hours. Prerequisites: Physics 319 and 325 and coregistration in Mathematics 415 or 423, or consent of the instructor. M 1:25 and T Th S 11:15. Mr. Nelkin.

Mechanics (about seven weeks): variational principles, Langrangian mechanics with applications, Hamiltonian mechanics and Poisson brackets, small vibrations and normal modes, and symmetry principles. Electrodynamics (about eight weeks): Maxwell's equations, electromagnetic potentials, stress energy, wave guides, wave propagation, and plasmas. At the level of *Mechanics* by Landau and Lifshitz and of *Electricity and Magnetism* by Jackson.

562. THEORETICAL PHYSICS II

Spring term. Credit four hours. Prerequisites: Physics 561 and either 443 or coregistration in Physics 572, or consent of the instructor. M 1:25 and T Th S 11:15. Mr. Chester.

Electrodynamics and relativity (about six weeks): radiation, Lienard-Wiechert potentials, multipoles, relativity, and relativistic applications. Statistical physics (about nine weeks): laws of thermodynamics, introduction to phase change, ensemble theory, thermodynamic fluctuations, Fermi-Dirac and Einstein-Bose statistics with applications, transport phenomena, and interacting systems. At the level of *Electricity and Magnetism* by Jackson and of *Statistical Physics* by Landau and Lifshitz.

[566. TOPICS IN THEORETICAL ASTROPHYSICS]

Spring term. Credit three hours. Prerequisite: graduate student status with a good background in physics, or consent of the instructor. This course and Astronomy 560 alternate by year. M Th F 1:25. Mr. Salpeter. Not offered in 1968–69.

Typical topics are: theory of stellar structure, theory of stellar atmospheres, and theories of interstellar medium. Topics and their treatment will vary from year to year.

572. QUANTUM MECHANICS

Either term. Credit four hours. Prerequisites: Physics 443, 561 (or 432), and at least coregistration in Mathematics 415 or 423, or consent of the instructor. M W F 11:15 and S 9:05. Fall term, Mr. Salpeter. Spring term, Mr. Bethe.

Principles of wave mechanics. Illustrative solutions of the Schrödinger equation, scattering, Dirac's formulation of quantum mechanics, transformation theory, and approximation methods. Symmetries: angular momentum, spin, the exclusion principle. At the level of *Quantum Mechanics,* Vol. I and part of Vol II, by Messiah.

574. INTERMEDIATE QUANTUM MECHANICS

Spring term. Credit four hours. Prerequisites: Physics 572 and at least coregistration in Physics 562 and in Mathematics 416, or consent of the instructor. M W F S 10:10. Mr. K. Wilson.

Discussion of various applications of quantum mechanics such as collision theory, theory of spectra of atoms and molecules, theory of solids, emission of radiation, and relativistic quantum mechanics. At the level of *Quantum Mechanics of One- and Two-Electron Atoms* by Bethe and Salpeter.

612. EXPERIMENTAL ATOMIC AND SOLID STATE PHYSICS

Spring term. Credit three hours. Prerequisites: Physics 510, 561, and 562, or consent of the instructor. M W F 2:30. Mr. Fitchen and staff.

Lectures on techniques and design principles, with emphasis on the study of solids by their interactions with electromagnetic fields. Topics include sources and detectors, scanning and resonance techniques, signal-processing, sample characterization, and environmental control. Illustrative examples from the recent literature are studied in detail.

614. EXPERIMENTAL HIGH-ENERGY PHYSICS

Spring term. Credit three hours. Prerequisites: Physics 510, 561, and 562, or consent of the instructor. Two lectures and one problem discussion section per week. T Th F 1:25. Mr. Browman and staff.

Design principles of high-energy apparatus: accelerators, beam transport, detection systems, etc., with examples of their applications. Practice in the use of relativistic kinematics. Statistical analysis in the design and interpretation of experiments. Discussion of the pitfalls encountered in actual experiments, with examples from the recent literature.

635. SOLID STATE PHYSICS I

Fall term. Credit three hours. Prerequisites: Physics 572 and statistical physics at the level of Physics 562, or consent of the instructor. T Th S 11:15. Mr. Bowers and staff.

An introduction to solid state physics including studies of lattice vibrations, the electronic structure of metals and of insulators, with applications to electrical, thermal, and transport properties.

636. SOLID STATE PHYSICS II

Spring term. Credit three hours. Prerequisite: Physics 635 or consent of the instructor. T Th S 11:15. Mr. Mermin.

The concepts developed in Physics 635 are extended and applied to a survey of some of the following: the Fermi surface in metals, localized states, magnetism, neutron and light scattering, and phenomenological superconductivity.

645. NUCLEAR PHYSICS

Fall term. Credit three hours. Prerequisite: Physics 572 or consent of the instructor. M W F 11:15. Mr. Hand.

Properties of nuclei, detection of particles, alpha decay, fission and thermonuclear reactions, gamma decay, beta decay, two-nucleon systems, nuclear models, and nuclear reactions.

646. HIGH-ENERGY PARTICLE PHYSICS

Spring term. Credit three hours. Prerequisite: Physics 574 or 645 or consent of the instructor. M W F 11:15. Mr. Silverman.

The physics of nucleons, mesons, and strange particles from an experimental point of view. High-energy phenomena, as opposed to classical nuclear physics, will be stressed. At the level of *An Introduction to Elementary Particles* by Williams.

NOTE: In courses above 650 the final grades will be only S or U.

651. ADVANCED QUANTUM MECHANICS

Fall term. Credit three hours. Prerequisite: Physics 574 or consent of the instructor. M W F 10:10. Mr. Kinoshita.

Relativistic quantum mechanics with emphasis on perturbation techniques. Extensive applications to quantum electrodynamics. Introduction to renormalization theory. At the level of *Relativistic Quantum Mechanics* by Bjorken and Drell.

652. QUANTUM FIELD THEORY

Spring term. Credit three hours. Prerequisite: Physics 651 or consent of the instructor. M W F 10:10. Mr. Yennie.

Canonical field theory, model field theories, Green's functions, renormalization. Introduction to analytic properties of scattering amplitudes and dispersion relations. Applications to strong interactions. At the level of *Relativistic Quantum Fields* by Bjorken and Drell.

653. STATISTICAL PHYSICS

Fall term. Credit three hours. Prerequisites: Physics 562 and 572, or consent of the instructor. T Th S 10:10. Mr. Wilkins.

A survey of topics in contemporary statistical physics, such as the Boltzmann equation, plasmas, sound propagation, phenomenological Fermi liquid theory, critical phenomena of simple fluids and ferromagnetics, classical fluids, introduction to Kubo formulae and Green's functions, and superfluids. At the level of *Statistical Physics* by Landau and Lifshitz.

654. THEORY OF MANY-PARTICLE SYSTEMS

Spring term. Credit three hours. Prerequisites: Physics 635 and 653, or consent of the instructor. T Th S 10:10. Mr. Ambegaokar.

The equilibrium and transport properties of microscopic systems of many particles are studied at zero and finite temperatures. The thermodynamic Green's function techniques are developed and applied to a variety of systems. Probable topics for discussion are the electron gas at high densities, the normal Fermi liquid, superconductivity, ferromagnetism, and the anharmonic crystal.

[657. THEORY OF NUCLEI]

Fall term. Credit three hours. Prerequisites: Physics 574 and 645, or consent of the instructor. Offered in alternate years and only if registration exceeds nine students. M W F 9:05. Mr. Bethe. Not offered in 1967–68.

661. HIGH-ENERGY PHENOMENA

Fall term. Credit three hours. Prerequisite: Physics 651 or consent of the instructor. Offered only if registration exceeds nine students. M W F 10:10. Mr. Gottfried.

Topics of current interest in the theory of strong interactions. At the level of *Dispersion Relations* by Klein.

680. SPECIAL TOPICS

Either term. Credit one to three hours a term. Upon sufficient demand, seminars will be arranged in topics not currently covered in regular courses. Typical topics are group theory, analyticity, weak interactions, superfluids, stellar structure and evolution, plasma physics, cosmic rays, relativity theory, low-temperature physics, x ray spectroscopy or diffraction, magnetic resonance, etc. For 1967–68: Fall term: Real Metals, Messrs. Wilkins and Ashcroft; and Dynamics of Strong Interactions, Mr. Gross. Spring term: Theory of Liquids, Mr. Egelstaff; Recent Developments in Quantum Field Theory, Mr. Kinoshita; and Collective Excitations (Phonons, Spinwaves, etc.) in Condensed Materials and Their Experimental Properties, Mr. Krumhansl.

690. INDEPENDENT STUDY IN PHYSICS

Either term. Credit one to three hours a term. Special study in some branch of physics, either theoretical or experimental, under the direction of any professorial member of the staff. Permission of the staff member under whose direction the work is to be done *must be obtained before registration.*

Graduate Student Statistics

Number of full-time graduate physics students: about 210
Number of part-time graduate physics students: about 1
Number of graduate fellows in physics: about 60
Number of first-year graduate physics students: about 60
Number of Ph.D. degrees granted in physics each year: about 27
Median number of years spent in graduate study by those receiving the Ph.D. degree in physics: about 5.0

The faculty is unanimous in the conviction that five years between the Bachelor's and the Ph.D. degree is too long; efforts are under way to reduce this median time.

FURTHER INFORMATION. A copy of the brochure *Graduate Study in Physics at Cornell,* containing additional information for the prospective graduate student, along with materials needed to file an application for an assistantship, may be obtained by writing to the Chairman of the Department of Physics, Clark Hall.

STATISTICS

Faculty: Robert E. Bechhofer, Isadore Blumen, Lawrence D. Brown, Roger Farrell, Walter T. Federer, Harry Kesten, Jack Kiefer, Philip J. McCarthy, Narahari U. Prabhu, Douglas S. Robson, Shayle R. Searle, Frank L. Spitzer, Bernt P. Stigum, Howard M. Taylor III, N. Scott Urquhart, Lionel Weiss, Jacob Wolfowitz.

Field Representative: Isadore Blumen, 360 Ives Hall.

MAJOR SUBJECT

Statistics

MINOR SUBJECTS

Provisions for minoring in statistics are given in the descriptions of the Fields of Operations Research, Industrial and Labor Relations, Mathematics, and Plant Breeding and Biometry contained in the Announcements of the various Areas of the Graduate School.

ADMISSION REQUIREMENTS. Since one of the principal aims of graduate work in the Field of Statistics is that of training individuals who will have a thorough knowledge of the theoretical basis of modern statistical method and will have demonstrated ability to make significant contributions to this theory, applicants should ordinarily have obtained nearly the equivalent of an undergraduate major in mathematics. It is strongly recommended that applicants resident in the United States during the year before entering the Graduate School present scores on the Graduate Record Examination Aptitude Test.

LANGUAGE REQUIREMENT. There is no foreign language requirement for the M.S. degree. A candidate for the Ph.D. degree must demonstrate reading ability in one language besides English, chosen from among French, German, or Russian.

PROGRAM OF STUDY. A student majoring in the Field of Statistics must complete a graduate sequence of courses in mathematical statistics which

has been approved by his Special Committee. Other course work required of majors in statistics will be chosen from among the offerings, as listed below, of the members of the Field. A doctoral student in the Field of Statistics ordinarily has two minor subjects but may, in consultation with the chairman of his Special Committee, choose to work in one minor subject. One minor subject will often be in an area of interest to the student in which the methods of statistics find extensive application. A second minor is usually devoted to mathematics, computing, or a similar subject.

PH.D. EXAMINATIONS. In addition to the Admission to Candidacy Examination, which will ordinarily be administered by the student's Special Committee during or at the end of the third year of graduate study, and the Final Examination on the thesis, the student will be given a qualifying examination. This examination will occur shortly after the first year of graduate study. It will serve to determine the ability of the candidate to pursue doctoral studies and to assist the Special Committee in developing a program of study for the candidate.

Teaching and Research Interests of the Faculty

In extremely broad terms, the teaching and research interests of faculty members are in the following general areas: biological applications of probability and statistics (Federer, Robson, Searle, Urquhart); engineering and operations research applications of probability and statistics (Bechhofer, Prabhu, Taylor, Weiss); mathematical theory of probability and statistics (Brown, Farrell, Kesten, Kiefer, Spitzer, Wolfowitz); social science applications of probability and statistics (Blumen, McCarthy, Stigum).

Some of the more specific areas of current interest are: analysis and probability theory (Kesten, Spitzer); design and analysis of experiments (Bechhofer, Federer, Kiefer, Robson, Searle, Urquhart, Wolfowitz); econometrics (Stigum); high speed computing (Searle); mathematical theory of statistics (Farrell, Kiefer, Wolfowitz); multiple decision procedures (Bechhofer); multivariate analysis (Blumen, Urquhart); nonparametric statistics (Blumen, Weiss); queuing and inventory theory (Prabhu); sampling theory (McCarthy, Robson); sequential sampling methods (Kiefer, Weiss); statistical control theory (Taylor); statistical genetics (Federer, Robson, Searle).

Courses

Descriptions of the following courses may be found in the Announcements of the various Areas of the Graduate School under the Fields with which they are identified; in those sections reference is also made to several advanced seminars, both formal and informal, the content of which varies from year to year.

Advanced Undergraduate and Master's Level Courses

OPERATIONS RESEARCH

9460. INTRODUCTION TO PROBABILITY THEORY WITH ENGINEERING APPLICATIONS

9470. INTRODUCTION TO STATISTICAL THEORY WITH ENGINEERING APPLICATIONS

9512. STATISTICAL METHODS IN QUALITY AND RELIABILITY CONTROL

9570. INTERMEDIATE ENGINEERING STATISTICS

INDUSTRIAL AND LABOR RELATIONS

310. DESIGN OF SAMPLE SURVEYS

311. STATISTICS II

410. TECHNIQUES OF MULTIVARIATE ANALYSIS

411. STATISTICAL ANALYSIS OF QUALITATIVE DATA

MATHEMATICS

371. BASIC PROBABILITY

472. STATISTICS

PLANT BREEDING AND BIOMETRY

410–411. MATHEMATICAL AND STATISTICAL MODELS IN BIOLOGY

417. MATRIX ALGEBRA IN BIOLOGY AND STATISTICS

510. STATISTICAL METHODS I

511. STATISTICAL METHODS II

Advanced Master's and Doctor's Level Courses

OPERATIONS RESEARCH

9560. APPLIED STOCHASTIC PROCESSES

9561. QUEUING THEORY

9564. STATISTICAL ASPECTS OF RELIABILITY ANALYSIS

9571. ADVANCED INDUSTRIAL AND ENGINEERING STATISTICS

9572. STATISTICAL DECISION THEORY

9573. STATISTICAL MULTIPLE DECISION PROCEDURES

INDUSTRIAL AND LABOR RELATIONS

610. ECONOMIC AND SOCIAL STATISTICS

614. THEORY OF SAMPLING

MATHEMATICS

571. PROBABILITY

572. STATISTIAL INFERENCE

574. ADVANCED PROBABILITY

575. INFORMATION THEORY

673. ANALYSIS OF VARIANCE

674. DESIGN OF EXPERIMENTS

675. STATISTICAL ESTIMATION

676. DECISION FUNCTIONS

677–678. STOCHASTIC PROCESSES

PLANT BREEDING AND BIOMETRY

513. DESIGN OF EXPERIMENTS I

514. DESIGN OF EXPERIMENTS II

517. LINEAR ESTIMATION AND TESTS OF HYPOTHESIS

518. SPECIAL TOPICS IN SEQUENTIAL SAMPLING, BIOASSAY, NONPARAMETRIC STATISTICS, ETC.

519. STATISTICAL GENETICS

THEORETICAL AND APPLIED MECHANICS

Faculty: Kyle T. Alfriend, Henry D. Block, Harry D. Conway, Edmund T. Cranch, Herbert H. Johnson, Richard H. Lance, Geoffrey S. S. Ludford, John P. Moran, John R. Moynihan, Yih-Hsing Pao, David N. Robinson.

Visiting Faculty: Michael D. Greenberg, Robin J. Knops.

Field Representative: Yih-Hsing Pao, 237 Thurston Hall.

MAJOR AND MINOR SUBJECTS

Fluid Mechanics
Mechanics of Materials
Solid Mechanics

The graduate program in mechanics emphasizes fundamental understanding of the newest developments in engineering and applied science. Graduate students may pursue in depth mechanics of liquids, gases, particles, rigid and deformable solids and related areas of materials, mathematics, and physics. The analytical and experimental nature of the studies encourages research that cuts across various fields. Graduate students pursue programs in the following areas of specialization: (1) space mechanics — including research on trajectories and orbits of space vehicles and satellites as well as the theory of light-weight, thin-walled structures; (2) wave propagation in solids — with research on the dynamic response of plates, structures, and machine elements;

(3) structural mechanics including static and dynamic loading, vibrations, and buckling; (4) theory of elasticity and plasticity; (5) theoretical fluid mechanics — with research in magnetohydrodynamics.

The flexibility of the M.S. and Ph.D. programs in mechanics permits students to draw on several divisions of the University for supporting work in pure and applied science. Graduate students in theoretical and applied mechanics and applied mathematics find these allied subjects of interest: mathematics, structures, engineering physics, servomechanisms, machine design, aerospace engineering, soil mechanics, and physics. To encourage the development of broad interests and skills a student normally is expected to select his two minors from approved subjects in other Fields.

Students whose major is engineering, physics, or applied mathematics are encouraged to apply for admission. The Field basically requires a mature and sound background in mechanics and mathematics but expects the applicant to satisfy no additional formal entrance qualifications beyond those of the Graduate School. (See Admission, pages 6–8.)

The Field of Theoretical and Applied Mechanics requires that each doctoral candidate demonstrate reading ability in one language other than his native language. Examination policy for proficiency is set by the Language Board of the Graduate School. The language selected must be approved by the Special Committee.

The Field of Theoretical and Applied Mechanics regards teaching experience as an essential part of the academic training of all doctoral candidates and hence makes such experience a requirement for the degree. Students admitted with advanced standing may receive credit for teaching experience acquired elsewhere.

Financial aid for students in the Field consists of University fellowships, teaching fellowships in the Department of Theoretical and Applied Mechanics, and a limited number of research assistantships in the same Department. Letters of application for financial aid should be submitted to the Graduate Field Representative.

Courses

1159. EXPERIMENTAL MECHANICS

Credit three hrs. Fall. One recitation, two laboratories. Primarily for graduate students and qualified undergraduates. Mr. Robinson.

Brittle coating method of experimental stress analysis. Electrical resistance type strain gages, including factors influencing alloy sensitivity, gage construction, gage factors, and stress gages. Instrumentation for static and dynamic strain gage work including a brief coverage of amplifiers, galvanometers, recorders, and oscilloscopes. Photoelastic methods of stress analysis, photostress.

1160. CONTINUUM MECHANICS

Credit three hrs. Fall. Three lectures. Graduates and qualified undergraduates. Mr. Knops.

A unified approach to the theory of continuous media based on thermodynamic and invariant principles. Kinematics of the continuum, stress hypothesis, uniqueness, constituitive equations. Special topics and examples from finite elasticity theory, the Navier-Stokes fluid and plasticity.

1162. VIBRATION OF ELASTIC SYSTEMS

Credit four hrs. Spring. Three lectures and one laboratory. Graduates and qualified undergraduates. Mr. Pao.

Review of vibration of linear lumped system with emphasis on matrix method and transient phenomena. Free and forced vibration of continuous systems, including strings, rods, beams, membranes, and plates. Waves in rods and beams. Orthogonality conditions and application of generalized functions. Rayleigh-Ritz method. Mathieu function and dynamic instability of strings, columns and other elastic systems. Nonlinear phenomena.

1163. APPLIED ELASTICITY

Credit three hrs. Fall. Three lectures. Graduates and qualified undergraduates. Offered in alternate years beginning 1967–68. Mr. Conway.

Analysis of thin curved bars. Plane stress and plane strain in the circular cylinder, effects of pressure, rotation, and thermal stress. Small and large deflection theory of plates, classical and approximate methods. Strain energy methods. Symmetrically loaded thin cylindrical shell. Torsion of thin-walled members. A first course in the mechanics of elastic deformable bodies with structural applications.

1164. THEORY OF ELASTICITY I

Credit three hrs. Spring. Three lectures. Offered in alternate years beginning 1967–68. Mr. Conway.

General analysis of stress and strain. Plane stress and strain. Airey's stress function solutions using Fourier series, Fourier integral, and approximate methods. St. Venant and Michell torsion theory. Simple three-dimensional solutions. Bending of prismatical bars. Axially loaded circular cylinder and half space.

[1165. THEORY OF ELASTICITY II]

Credit three hrs. Spring. Three lectures. Not offered in 1967–68.

Development in tensor form of the basic equations of large deformation elasticity; solution of certain large deformation problems. Linearization to infinitesimal elasticity. Boussinesq-Papkovich potentials and their application to three-dimensional problems; contact problems; plane stress by method of Muskhelishvili; application of conformal mapping; Cauchy integral techniques in elasticity; torsion problems.

1166. STRESS WAVES IN SOLIDS

Credit three hrs. Spring. Three lectures. Prerequisites: 1162, 1163, or equivalent. Offered in alternate years beginning 1967–68. Mr. Robinson.

General equations of elastodynamics. Waves in extended elastic media. Reflection and refraction of waves. Surface waves and waves in layered media. Vibrations and waves in strings, rods, beams and plates. Dispersion in mechanical wave-guides. Transient loads. Scattering of elastic waves and dynamical stress concentration. Waves in anisotropic media and visco-elastic media.

[1167. STABILITY THEORY OF PLATES AND SHELLS]

Credit three hrs. Spring. Three lectures. Graduates and qualified undergraduates. Not offered in 1967–68.

General formulation of equations and criteria for static and dynamic stability of plates and shells. Energy methods. Conservative and nonconservative loading. Membrane and bending stresses and displacements. Applications to the buckling of plate and shell type structures.

[1168. THEORY OF PLASTICITY]

Credit three hrs. Spring. Three lectures. Graduate students and qualified undergraduates. Not offered in 1967–68.

Theory of inelastic behavior of materials. Plastic stress-strain laws, yield criteria and flow laws. Flexure and torsion of bars, thick-walled cylinders, metal forming and cutting, stress analysis in metals and soils. Yield hinges. Limit analysis. Shakedown of simple statically indeterminate members.

1170. ADVANCED DYNAMICS

Credit three hrs. Fall. Three lectures. Graduate students and qualified undergraduates. Mr. Lance.

Newton's equations of motion for a system of masses, their solution, momentum, energy. Systems with variable mass, rocket equations. Variational principles of mechanics, d'Alembert's principle, Lagrange's equations, Hamilton's equations. Stability of motion, Liapunov's method. Rigid body motion, Euler's equations, tops, gyroscopes. Theory of small oscillations.

1172. SPACE FLIGHT MECHANICS

Credit three hrs. Spring. Three lectures. Graduate students and qualified undergraduates. Mr. Alfriend.

Three-body problem; regularization; Jacobi integral; restricted three-body problem; Hill curves; libration points and stability; motion in cislunar space; interplanetary trajectories; space navigation; limiting problems in space travel; theory of optimal trajectories; Pontryagin maximum principle; rendezvous problems.

1180. METHODS OF APPLIED MATHEMATICS I

Credit three hrs. Fall. Three lectures. Prerequisite: one-semester course in ordinary and partial differential equations. Mr. Greenberg.

Ordinary differential equations; series; orthogonal functions and Sturm-Liouville theory; Green's function; Fourier and Laplace transforms; functions of several real variables; vector analysis; matrices; partial differential equations; with application to engineering problems.

1181. METHODS OF APPLIED MATHEMATICS II

Credit three hrs. Spring. Three lectures. Prerequisite: 1180. Mr. Greenberg.

Continuation, from 1180, of partial differential equations; complex variable; tensor analysis; calculus of variations with application to engineering problems.

1182. METHODS OF APPLIED MATHEMATICS III

Credit three hrs. Fall. Three lectures. Prerequisite: 1181 or equivalent. Mr. Ludford.

Application of advanced mathematical techniques to engineering problems. Conformal mapping; complex integral calculus; Green's function; integral transforms; asymptotics including steepest descent and stationary phase; Wiener-Hopf technique; general theory of characteristics; perturbation methods; singular perturbations including PLK method and boundary layers. Development will be in terms of problems drawn from vibrations and acoustics, fluid mechanics and elasticity, heat transfer, electro-magnetics.

1183. METHODS OF APPLIED MATHEMATICS IV

Credit three hrs. Spring. Three lectures. Prerequisite: 1182 or equivalent. Mr. Ludford.

More extensive treatment of 1182 in same spirit. Topics include: method of matched asymptotic expansions, W.K.B. approximation; Hilbert-Schmidt and Fredholm theories of integral equations; singular integral equations. Wiener-Hopf equations with application to finite interval, Carleman equation

and its generalization, effective approximations; further methods in partial differential equations, slot problems.

1184. NUMERICAL METHODS IN ENGINEERING

Credit four hrs. Spring. Prerequisite: 1181 or equivalent. Mr. Moran.

Methods for obtaining numerical solutions to problems arising in engineering and for evaluating analytical solutions numerically. Accelerating convergence of series solutions; continued fractions, quotient-difference algorithms. Solution of initial-value and boundary-value problems for ordinary differential equations. Quadrature; solution of integral equations. Direct and iterative methods for solving algebraic equations and systems of equations. Eigenvalue problems. Partial differential equations; finite-difference methods, method of characteristics, integral methods.

1196. RESEARCH IN THEORETICAL AND APPLIED MECHANICS

Credit as arranged. Staff.

Thesis or independent research in a field of theoretical and applied mechanics. Such research must be under the guidance of a staff member.

1197. SELECTED TOPICS IN THEORETICAL AND APPLIED MECHANICS

Credit as arranged, any term. Staff.

Qualified students wishing to do work in any field of theoretical and applied mechanics should register for this course after consultation with the department. Students work with appropriate members of the staff in the chosen field. Typical areas of work include theory of elastic stability, theory of plates and shells, rocket theory and design, wave propagation, elasticity, vibrations, and experimental mechanics.

WATER RESOURCES

Faculty: David J. Allee, Richard D. Black, Leonard B. Dworsky, Alfred W. Eipper, Louis M. Falkson, Charles D. Gates, Lawrence S. Hamilton, George A. Kiersch, Gilbert Levine, Daniel P. Loucks, Walter R. Lynn, Paul J. Zwerman.

Field Representative: C. D. Gates, 223 Hollister Hall.

MINOR SUBJECT

Water Resources

This Field offers qualified engineers and biological, physical, and social scientists an opportunity to gain breadth of knowledge in water resources planning and management at the same time that they increase their depth of knowledge in their own disciplines. Study in the major subject is complemented by an integrated and interdisciplinary program of study in a minor subject designated as water resources and required of all candidates choosing this Field.

The water resources minor will represent for each candidate that combination of courses, including core courses, seminars, and projects, outside his own discipline, which, in the judgment of his committee, is most likely to meet his needs and interests in the comprehensive aspects of his program.

Complementing major and minor subjects ordinarily will be chosen from the following list (Fields and faculty as shown):

Aerial photographic studies (Civil Engineering): D. J. Belcher, T. Liang, G. B. Lyon, A. J. McNair.

Chemical engineering (Chemical Engineering): R. K. Finn, H. F. Wiegandt.

Econometrics and economic statistics (Economics): T. C. Liu.

Economic theory (Economics): L. M. Falkson, B. P. Stigum, J. Vanek.

Environmental systems engineering (Civil Engineering); L. M. Falkson, W. R. Lynn.

Fishery biology (Conservation): A. W. Eipper, J. L. Forney, D. A. Webster.

Geohydrology (Geological Sciences): G. A. Kiersch, S. S. Philbrick.

Hydraulics and hydrology (Civil Engineering): W. H. Brutsaert, W. H. Graf, J. A. Liggett.

Hydrogeology and engineering geology (Geological Sciences): G. A. Kiersch, S. S. Philbrick.

Limnology (Entomology and Limnology): C. O. Berg, D. J. Hall, J. M. Kingsbury.

Meteorology (Agronomy): B. E. Dethier.

Natural resources conservation (Conservation): L. S. Hamilton.

Oceanography (Ecology and Evolutionary Biology): J. P. Barlow.

Operations research (Operations Research): R. W. Conway, W. L. Maxwell, B. W. Saunders, H. M. Taylor.

Public administration (Business and Public Administration): E. S. Flash.

Public finance (Economics): R. W. Kilpatrick.

Regional planning (City and Regional Planning): J. C. Fisher, B. G. Jones, K. C. Parsons, J. W. Reps.

Resource economics (Agricultural Economics): D. J. Allee.

Sanitary engineering (Civil Engineering): V. C. Behn, L. B. Dworsky, C. D. Gates, A. W. Lawrence, D. P. Loucks.

Soil and water engineering (Agricultural Engineering): R. D. Black, G. Levine.

Soils (Agronomy): M. G. Cline, H. A. Kerr, R. D. Miller, H. F. Mulligan, P. J. Zwerman.

ADVANCED PROFESSIONAL DEGREES

Advanced professional degrees are designed as preparation and training for a special profession.* The admissions, requirements, and curricula for such degrees, as approved by the Graduate Faculty, are announced by the faculty of a professional school or college, which, for this purpose, acts as a Division of the Graduate Faculty. Degrees are awarded upon recommendation of the Division to the Graduate Faculty. Detailed information regarding admission or academic requirements for any professional degree is included in the Announcement of the separate school or college in which the degree is offered. Inquiries addressed to the Graduate School will be forwarded to the proper official. The professional degrees listed below are approved by the Graduate Faculty.

ARCHITECTURE, FINE ARTS, REGIONAL PLANNING

The following three degrees are administered by the Division of Architecture and Fine Arts of the Graduate School. Inquiries should be addressed to the listed professor.

For more detailed information on these degrees, as well as those in architectural structures, architectural history, and art, see also two *Announcements of the Graduate School: Humanities* and *Social Sciences.*

MASTER OF ARCHITECTURE (M.Arch.). Training in urban design. Only graduates of a five-year professional program in architecture or graduates of a program in city planning or landscape architecture are admitted as candidates. (Professor Colin Rowe.)

MASTER OF FINE ARTS (M.F.A.). Advanced training in the practice of painting, sculpture, or graphic arts. (Professor James O. Mahoney.)

MASTER OF REGIONAL PLANNING (M.R.P.). Training for a professional career in the field of city planning or regional planning. (Professor Kermit C. Parsons.)

EDUCATION

Two professional degrees are administered by the Field of Education of the Graduate School. The programs leading to each of the degrees in-

* The following are advanced degrees which are also first degrees of a school or college and therefore are not subject to the jurisdiction of the Graduate Faculty. For information regarding them, address the school or college indicated.

Bachelor of Laws ..... Law School
Master of Engineering (Aerospace) ..... Graduate School of Aerospace Engineering
Master of Business Administration, Master of Public Administration ..... Graduate School of Business and Public Administration
Doctor of Medicine ..... Medical College, New York City
Doctor of Veterinary Medicine ..... Veterinary College

clude courses, seminars, projects, and investigations which will develop the student's ability to perform acceptably the professional duties required of the several types of educational specialization.

MASTER OF ARTS IN TEACHING (M.A. in T.). This program is designed for and limited to those preparing for teaching in elementary and secondary schools. The student and his Special Committee will select those courses and seminars in his teaching specialty and in Education which are deemed most appropriate for developing competence as a teacher. The student will be required to demonstrate his or her teaching skill in a supervised field experience. Completion of a twelve-month program, or two and two-fifths residence units is required.

DOCTOR OF EDUCATION (Ed.D.). The program for this degree is designed to prepare the candidate within a broad cultural context for positions of professional leadership in education. The program of studies must include advanced work in each of the following: educational psychology, history or philosophy of education, educational measurement and statistics, and research in education. At least fifteen hours of credit must be earned in courses other than those in professional education. A minimum of sixty-five credit hours beyond the Bachelor's degree is required, of which thirty-five hours should be completed beyond the Master's degree or its equivalent. A candidate is required to complete a minimum of five residence units beyond the Bachelor's degree and a year of directed field experience.

Professional Teaching

MASTER OF SCIENCE FOR TEACHERS (M.S.T.). This is a coordinated program of training in the biological and physical sciences for prospective and practicing teachers. Each degree candidate must satisfy a broad core program in mathematics and science and complete advanced work in his selected Field of study. This degree is administered by the Division of Professional Teaching of the Graduate School. Detailed information may be obtained from the Graduate School Office, Sage Graduate Center.

ENGINEERING

The degree of Master of Engineering is administered by the Engineering Division of the Graduate School. Specially oriented graduate programs of study are in the areas of agricultural, chemical, civil, electrical, industrial, materials, mechanical, and nuclear engineering, and in engineering physics. The following titles designate the Professional Masters' degrees offered in engineering: Master of Engineering (Agricultural), Master of Engineering (Chemical), Master of Engineering (Civil), Master of Engineering (Electrical), Master of Engineering (Engineering Physics), Master of Engineering (Industrial), Master of Engineering (Materials), Master of Engineering (Mechanical), Master of Engineering (Nuclear).

The Graduate School of Aerospace Engineering administers the Master of Engineering (Aerospace) degree program.

The general requirements for the degrees listed above are:

1. A minimum of thirty credit hours of advanced technical course work in the specific field or in related subjects.
2. A minimum of three credit hours (included in the above) of engineering design experience involving individual effort and formal report.
3. A minimum grade point average of 2.5 and a minimum final grade of C minus for all courses counting toward the degree.

There are no residence requirements, although all course work must, in general, be completed under Cornell University staff instruction. The degree requirements must normally be completed within a period of four calendar years.

Graduates of Cornell University who hold Bachelor of Engineering degrees may be granted up to fifteen hours credit for advanced courses taken during their fifth undergraduate year, provided they enter the Master of Engineering program not later than the fall term following the sixth anniversary of their receiving the Bachelor of Engineering degree.

The *Announcement of the College of Engineering* should be consulted for further details on the professional Masters' programs in the various fields.

INDUSTRIAL AND LABOR RELATIONS

MASTER OF INDUSTRIAL AND LABOR RELATIONS (M.I.L.R.). The program leading to this degree provides a basic course of graduate study for those with professional interests in industrial and labor relations and further provides limited opportunities for specialized professional study where broad competence has been established. This degree is administered by the Division of Industrial and Labor Relations of the Graduate School. More information may be obtained by writing to the School of Industrial and Labor Relations, Ives Hall.

LAW

The following two degrees are administered by the Division of Law of the Graduate School. The *Announcement of the Law School* should be consulted for a complete description of the program and requirements.

MASTER OF LAWS (LL.M.). This degree is intended primarily for the student who desires to increase his knowledge of the law by working in a specialized field.

DOCTOR OF THE SCIENCE OF LAW (J.S.D.). This degree is intended primarily for the student who desires to become a proficient scholar by original investigation into the functions, administration, history, and progress of law.

MUSIC

DOCTOR OF MUSICAL ARTS (A.Mus.D.). This degree is appropriate for mature composers who seek further professional training as well as knowledge of the other arts and humanities, both to enrich their creative perspectives and to prepare them for the teaching of composition and theory at the university level. It is administered by the Department of Music, acting as a Division of the Graduate School for this purpose.

NUTRITIONAL AND FOOD SCIENCE

The following two degrees are administered by the Division of Nutrition of the Graduate School. More information may be obtained by writing to the Graduate School of Nutrition, Savage Hall.

MASTER OF NUTRITIONAL SCIENCE (M.N.S.). This program emphasizes fundamental study in the basic sciences that can lead to specialization in such areas as nutritional biochemistry, public health, nutrition, human and clinical nutrition, and international nutrition. In addition, for candidates interested in the biological sciences, the program serves as a valuable preliminary for more advanced graduate study.

MASTER OF FOOD SCIENCE (M.F.S.). The fundamental sciences, chemistry, biochemistry, and bacteriology, that are involved in food processing and utilization, are emphasized. Electives are available to meet individual needs in engineering, economics, marketing, business administration, and international programs. The specialized training serves as a preparation for technical work as related to the food industry or for more advanced graduate study.

VETERINARY MEDICINE

DOCTOR OF SCIENCE IN VETERINARY MEDICINE (D.Sc. in V.M.). This degree is characterized by a professional rather than a general research objective, and it is designed especially for experienced persons in the basic and clinical sciences who need more specific, advanced, scientific, and professional knowledge in order to equip themselves for careers in teaching and research. This degree is administered by the Division of Veterinary Medicine of the Graduate School.

The University expects that all graduate students at Cornell University shall, at all times, act with a mature and morally responsible attitude, recognizing the basic rules of society and the common rights of others.

Index of Fields of Instructions and Major and Minor Subjects

General Index